THE SOIL SCIENCE SOCIETY OF FLORIDA

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PROCEEDINGS
VOLUME XV
1955

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Fifteenth Annual Meeting of the Society
Orange Court Hotel
Orlando
November 29, 30 and December 1, 1955

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OFFICERS OF THE SOCIETY *

1956

* Retiring Officers listed on page 257

ACKNOWLEDGMENTS

It is the desire of the Executive Committee of the Society to express their appreciation and that of the entire membership to the Officials of Orange Court Hotel for the splendid manner in which they attended our every need throughout the course of the Fifteenth Annual Meeting of the Society. Their care of us could scarcely have been better. This, of course, includes the parallel helpfulness of the Orlando Chamber of Commerce and the very particular assistance extended by the local Convention Bureau at our registration desk.

Likewise it is the desire of the committee to tell Vice President Walter Reuther of its sincere thanks for the great and good effort he made, as program chairman, in planning and organizing the splendid series of symposia and other features of the program which was regarded by many of those present as one of our very best to date. General regret was expressed over the fact of his plans to leave Florida very shortly following the meetings which was to prevent his succeeding to the office of the President of the Society, an honor which he had so fully earned.

The particular thanks of the whole Society need also be recorded to Dr. Lorenzo A. Richards, Physicist, U. S. Salinity Laboratory, Riverside, California and to Dr. Robert L. Mitchell, Deputy Director of The Macaulay Institute for Soil Research, Aberdeen, Scotland, for the special effort they made to be with us and for the fine part they took in the program. The excellent papers they presented on the physics of irrigation and on the spectroanalysis of soil and plant materials, respectively, will prove an enduring contribution to the Soil and Crop Sciences of Florida.

Finally, the Executive Committee wishes to thank all those who took an active and thoughtful part in the two year campaign to change the name of the Society. It is recorded elsewhere in this volume that the ballot by mail showed a 2 to 1 return in favor of that change. And so it is a pleasure to here greet our organization as THE SOIL AND CROP SCIENCE SOCIETY OF FLORIDA under which name the program for the coming year will be developed. We are confident this important broadening of the scope of the subject matter of the Society will greatly enrich its future programs.

HONORARY LIFE MEMBERS

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1955

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Mathias, A. C., Box 337, Haines City
Matthews, Col. A. G., Division Water Surveys & Research, State Bd. of Conservation, Tallahassee
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Rodaniche, Dr. A., Jr., Box 466, Ancon, Canal Zone
Russell, Robert P., 30 Rockefeller Plaza, Room 5101, New York 20, New York
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Seitz, Dr. Edward, % Amboni Estates, Ltd., Box 117, Tanga, Tanganyika, East Africa
Sexton, W. E., Vero Beach
Shawano Development Corp., 70 Wall St., New York, N. Y.
Shawmut Engineering Co., 179-195 Freeport St., Boston 22, Mass.
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United States Phosphoric Products, P. O. Box 3269, Tampa
United States Sugar Corporation, Clewiston
Waring, W. L., Lyons Fertilizer Company, P. O. Box 310, Tampa
Washington Technical Services, 810 18th Street. N.W., Washington 6, D. C.
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Winter Haven Citrus Growers Assn., Box 312, Winter Haven
Woods, F. J. and L. P., P. O. Box 2721, Tampa
Woodward, William D., Box 428, Quincy
Zipperer, J. O., P. O. Box 632, Fort Myers

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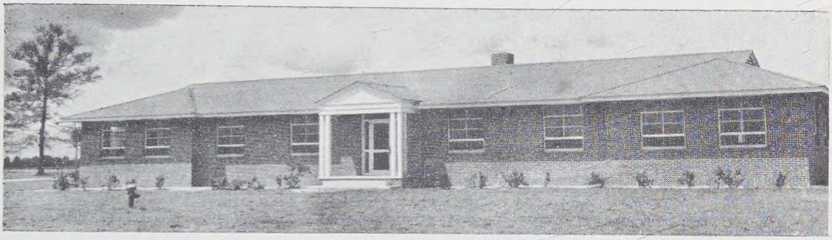
INTERIM (SPRING) MEETING

North Florida Experiment Station
Quincy, April 7-9, 1955



Jacob Dewey Warner Laboratory, North Florida Experiment Station, Quincy, Florida.

PROGRAM

APRIL 7—7:00 P.M.

Tour of Budd Cigar Factory

APRIL 8—8:30 A.M.-12:15 P.M.

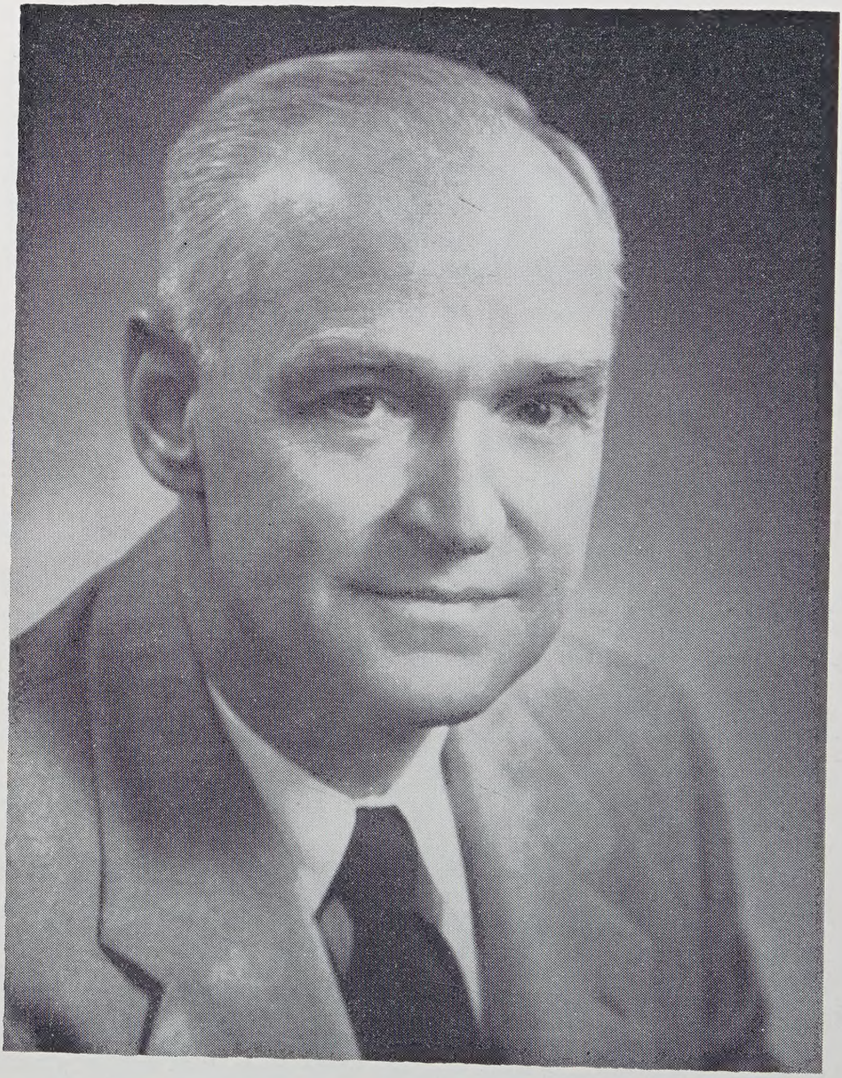
Registration—North Florida Experiment Station
Address of Welcome—C. W. Thomas, Jr., local business man and farmer, Mayor of the City of Quincy
Guest Speaker—James J. Love, address on his tour of Europe on Special Committee of Agriculture appointed by President Eisenhower and Secretary of Agriculture Benson
W. H. Chapman, Small Grain Breeding Program
L. G. Thompson, Crop Rotation
T. E. Webb, Lupine and Soybean Program
F. S. Baker, Livestock and Pasture Program
R. W. Wallace, Fertilizer Experiments on Pasture and Shade Tobacco
R. R. Kincaid, Shade Tobacco Breeding Program and Disease Control of Shade Tobacco
W. C. Rhoades, Insect Control on Various Crops in Northwest Florida
R. W. Lipscomb, Peanut Research Program and Crop Rotation
R. L. Smith, Mobile Unit Work in Escambia and Santa Rosa Counties
Announcements and Brief Business Meeting

12:15-5:30 P.M.

Lunch
Tour of Tobacco Division
Tour of Key Farm. Here you will see a large steer feeding project and soil conservation practices at their best in West Florida
Tour of North Florida Experiment Station Farm. Includes small grain nursery, pasture and livestock program, lupine nursery, pasture fertilization program and crop rotation experiments

April 9—9:00-12:00 Noon

Tour of other outstanding farms in area



DR. LORENZO A. RICHARDS

GUEST SPEAKER

BIOGRAPHICAL SKETCH — LORENZO A. RICHARDS

Dr. Richards was born in Fielding, Utah, April 24, 1904, and received his elementary training at Brigham City, Utah. He received the B.S. degree from Utah State College in 1926 and the M.A. degree from the same institution in 1927, majoring in physics. During the period 1927-1931 he was engaged in graduate studies at Cornell University, majoring in physics and received the Ph.D. degree in 1931.

From March, 1935 to September of that year, Dr. Richards was a research physicist at the Battelle Memorial Institute, Columbus, Ohio. From September, 1935 to June, 1939, he was on the staff of the Iowa State College where he attained the rank of Associate Professor. While there, he taught courses in physics and soil physics and conducted soil physics research in the Agricultural Experiment Station.

Dr. Richards joined the staff of the Salinity Laboratory, U. S. Department of Agriculture, in July 1939, at which place he has served as physicist until the present, except for war leave. From June 1942 to September 1945 he worked as a research associate at the California Institute of Technology on weapon development and received the Navy Department Ordnance Development Award and the Presidential Certificate of Merit.

Dr. Richards has been honored on several occasions for his achievements in the field of soil physics and for his contribution to the over-all field of soil science. He served as President of the Western Society of Soil Science in 1950 and was President of the Soil Science Society of America in 1952. In 1949 he was given the Stevenson Award of the American Society of Agronomy in recognition of his achievements in soil physics research and in 1953 was elected a Fellow in the American Society of Agronomy. In May, 1952, he received the honorary degree of Doctor of Technological Science from the Hebrew Institute of Technology, Haifa.

Dr. Richards has served on a number of national committees dealing with soil physics. In 1948 he was Chairman of the Committee on the Physics of Soil Moisture of the American Geophysical Union. He served as Chairman of the Committee on Technology and of the Subcommittee on Permeability and Infiltration and is now a member of the Committee on Membership Organization and Policy for the Soil Science Society of America. He has served on the Committee for the Nomination of Fellows and is now a member of the Committee on Publication Needs for the American Society of Agronomy. He has served as Vice Chairman of Commission 1 (Soil Physics) and as Chairman of the Committee on Saline Soils for the International Society of Soil Science. For several years he was an ex-officio member of the National Soil Research Committee through his chairmanship of the National Work Group on Soil Conditioners.

Dr. Richards has developed a number of instruments and types of apparatus that are widely used in soil physics and has published numerous research papers in this field.

DR. ROBERT L. MITCHELL

GUEST SPEAKER

BIOGRAPHICAL SKETCH — ROBERT L. MITCHELL

Dr. Robert L. Mitchell was born in Edinburgh, Scotland, in 1910, and educated at Bathgate Academy. He studied chemistry at the University of Edinburgh under Professor J. P. Kendall and graduated Bachelor of Science with First Class Honors in 1931, thereafter obtaining the degree of Doctor of Philosophy at the University of Aberdeen for a thesis dealing with the base status of Scottish soils, the work having been carried out at the Macaulay Institute for Soil Research in Aberdeen. In 1933 Dr. Mitchell spent a year at the Federal Technical High School in Zurich, working on colloidal problems under Professor Georg Wiegner.

On returning to the Macaulay Institute, Dr. Mitchell, after a year's experience of soil survey and pedological problems, introduced spectrochemical methods to the Institute in 1935, and has since been continuously engaged in the development of this work. He is now Deputy Director of the Institute and Head of the Department of Spectrochemistry in which some seven graduate workers and twelve assistants are engaged in trace element and spectrochemical investigations. The lines of work which have been developed are summarized in the interesting and valuable paper which he contributes to this volume on the pages that immediately follow under the title "Spectrographic Analysis of Plants and Soils."

Dr. Mitchell has spent short periods in the spectrochemical laboratories of Dr. Mannkopff in Gottingen and Professor Lundegardh in Stockholm, and has attended international conferences dealing with soils, plants, geochemistry and analytical chemistry. In the fall of 1955 he attended the Symposium on Trace Analysis in New York, and following this, in a tour of the United States sponsored by the Rockefeller Foundation, he was able to attend the meeting of the Soil and Crop Science Society of Florida in Orlando and to see something of trace element problems in Florida.

SPECTROCHEMICAL ANALYSIS OF PLANTS AND SOILS

R. L. Mitchell *

Spectrochemical methods of analysis of plants and soils have now been in use at the Macaulay Institute for over twenty years. They were adopted after the author had in 1933-34 seen the Lundegårdh flame technique in use in Wiegner's laboratory in Zurich, where Pallmann was using it to determine exchangeable cations. At that period, when quantitative spectrographic methods were in their infancy, there was little or no information on the determination of trace elements in plants or soils, and initially the work was restricted to the determination of such elements as K, Na, Ca, Mg, Sr and Mn in soil and plant extracts. It was at this time that high contents of Ni in some soils from northeast Scotland were observed by flame methods, and certain small infertile areas were later diagnosed as areas of nickel toxicity.

The Lundegårdh and other flame techniques are well adapted to the determination of the alkali and alkaline earth metals in solution at the levels commonly encountered in agricultural and biological investigations. Although many other elements, including Mn, Fe, Cu, Co, Ni, Pb, Cr, etc., are excited in the acetylene flame, of these only Mn is normally present in amount adequate for determination in such samples. In exceptional instances other elements, for instance Ni, Cu, Pb and Fe may be observed and determined in soil and plant extracts, and the fact that they can be seen if a spectrographic method is used, but are liable to be missed in a flame photometer unless specifically sought, is one argument in favor of the former for diagnostic work. For routine analysis for one or more specific elements the latter has, of course, much to commend it. Here in fact is an instance of two rather similar techniques being complementary, and at the Macaulay Institute both methods are employed.

In the Lundegårdh method a fine spray of the solution being analyzed is introduced into a bunsen type air-acetylene flame and the spectrogram recorded by a medium dispersion quartz spectrograph (2000-8000A on a 10 inch plate). We consider that the Lundegårdh type flame has certain advantages over the more compact, concentrated sources now often employed for flame photometers. In particular one can more readily choose a flame zone where interference effects and sensitivities are optimum for any specific investigation. There would appear to be little doubt that the hotter the flame zone examined the smaller the interferences due to complex formation—particularly those affecting Ca:Al and Ca:P.

Convenient concentrations for spectrographic analysis by the Lundegårdh technique, expressed in milligrams of element per 50 milliliters of solution, are:

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* Head, Department of Spectrochemistry and Deputy Director of The Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen, Scotland.

Element	λ	mg./50 ml.
Na	3302	0.5 -10
K	4044	0.5 -10
Li	6708	0.005- 0.1
Ca	4227	0.025- 0.5
Sr	4607	0.025- 0.5
Mg	2852	0.3 - 6
Mn	4031	0.03 - 0.6
Fe	3860	1 -20

It must be kept in mind that variations in flame setting, type of spectrograph, and photographic emulsion can modify the ranges covered. Such levels, other than that for Fe, are generally readily obtained in soil and plant extractions by suitable choice of aliquots. In addition to the Lundegårdh spectrographic technique, a flame photometer (Mitchell 1950) based on the Lundegardh type burner has been built by Dr. A. M. Ure and is in constant use, demand on it often exceeding one hundred samples per day. The Lundegardh air-acetylene burner was chosen because a considerable knowledge of its behaviour was available and much was known regarding the level of interference effects as a result of our earlier spectrographic work. Other types of burner would not appear to be markedly superior in operation, although some may work with much smaller volumes, a factor which is not normally important in our type of work.

This flame photometer has been in use continuously for over seven years. It is a three-channel instrument for Ca, Na and K. Ca and Na lines at 4227 and 5893 are isolated in a Hilger Wavelength Spectrometer and passed through exist slits to 931A photomultipliers, which are connected directly to shunted 450 ohm Cambridge Spot Galvanometers (2 μamp full scale deflexion). The red K lines are isolated by filters (Ilford 207 and Chance I. N. 20) and the emission converted to a green fluorescence by means of a small (CV 148) image converter of the type used in wartime infrared detectors. The fluorescence is measured by a 931A-galvanometer circuit similar to that used for Ca and K. Both K and Na can be determined at below 1 p.p.m. in solution, and Ca at 10 p.p.m., values which are convenient for the direct analysis of 2.5% acetic acid extracts of soils. Test runs with standard solutions indicate coefficients of variation of less than 2%, which is adequate for most work involving biological materials, where sampling errors exceed this.

For the determination of Mg in soil extracts a porous cup solution-spark technique has been found preferable to the Lundegårdh method. In the flame Mg is rather insensitive and accuracy is not satisfactory, even after 10-fold concentration of 2.5% acetic acid soil extracts. On the other hand, Mg is very sensitive and quite accurately determined by the porous cup technique in such acetic acid extracts without concentration. In this method a fraction of a millilitre (generally 0.1 ml.) of solution is introduced into a carbon or graphite electrode, about 5 mm. in outside diameter, which has been bored out (3 mm. diameter hole) until only a thin base 0.6 mm. in thickness remains. The total length of the electrode is 25 mm. When a condensed spark discharge passes over the 2 mm. gap between this upper electrode and a pointed solid carbon lower

electrode, the base of the cup is sufficiently porous to allow the entire solution to pass into the gap in about one minute.

The sensitivity of Mg is such that 0.1-10 p.p.m. in solution is readily determined, using Fe as internal standard. For routine determinations we use a Hilger Small Quartz Spectrograph, which is adequate for this specific purpose, but rather small for general use. With the Medium Quartz spectrograph, analyses of Cu and Zn in acetic acid extracts are being made by the porous cup technique after concentration to small volume. This method of excitation would appear to be suitable for the application of direct reading methods, and experiments along these lines are in progress.

For most trace elements, flame or spark excitation is not adequate, and the more sensitive arc excitation must be employed. In this technique a powder sample is filled into a boring in a carbon electrode and excited by the high temperature produced when a direct current arc is struck between the filled electrode and a solid upper electrode. The numbers of modifications of electrode dimensions and spacing and of current employed are such that only the methods in use at the Macaulay Institute can be considered here. Other methods have been reviewed in a recent publication (Mitchell 1954). The examination of plant materials and soil extracts for trace elements is not a straightforward process. In a spectrochemical analysis, determinations are generally made by comparison with the results obtained for standard mixtures covering the same range of contents; in such determinations the composition of the matrix, i.e., the amount of the various major constituents present, affects spectrographic results, even in an internal standard method in which the unknown element is compared with an element present in known amount. To avoid the effects due to variation in composition of plant ash it is possible, for some elements, to add an excess of spectroscopic buffer, such as K_2SO_4, to reduce the overall variation in matrix composition, but this is only possible if the content of the trace element is sufficiently high to permit the dilution with buffer to be made. A method for Cu, Mn, Ba and Sr in plant ash by this technique will be mentioned later.

Generally, however, it is better to bring the trace elements to be determined into a matrix of known, constant and desirable composition by some form of chemical pretreatment, particularly if at the same time, some degree of concentration can be effected. It is this procedure which has been adopted at the Macaulay Institute for the determination of such elements as Co, Ni, Mo, Sn, Pb, Zn, V, Ti, Cr, and Ag in plant materials and soil extracts. A method has been evolved (Mitchell and Scott 1948; Mitchell 1948) in which the above and a few other trace elements are precipitated by mixed organic reagents in an alumina matrix. This method has now been in use for over ten years and in practice has proved reliable, provided adequate attention is given to standardization and to preliminary purification of the materials required. It is not a method which can be set up and used efficiently in the course of a few weeks, and we do not recommend its adoption for the analysis of a limited number of samples on a short term basis, but if long term investigation on a routine scale, involving thousands of samples for a number of elements were envisaged, then we know of no other technique which is equally applicable. Even when the method is available, it may be preferable to use some other technique, such as a colorimetric determination, if only

a single element per sample be required. The decision must depend on the laboratory facilities and on the level at which the determination is to be made. It is when several elements are required in the same sample that spectrochemical methods are particularly valuable.

In order to obtain an adequate amount of such trace elements as Co or Mo it is generally necessary to start with 20 g. of plant dry matter. This is ashed overnight at 450°C. in a silica-lined muffle furnace, extracted with hydrochloric acid, and the residue re-ashed and fused with Na_2CO_3, the operations being carried out in platinum. To the combined hydrochloric acid extracts (about 150 ml.), which should contain about 15 mg. Al and 1.5-4 mg. Fe, are added 10-15 ml. 5% 8-hydroxyquinoline in 2N acetic acid, followed by 10N ammonia dropwise until a colour change from yellow to emerald green indicates a pH of 1.8-2.0. The solution is now buffered to a pH of 5.1-5.2 by 2N ammonium acetate, but this is normally done in stages. If only Co, Ni, Mo and Ti are required, precipitation is brought about by addition of 50 ml. of ammonium acetate which should give the required pH. If the other elements mentioned above are desired, tannic acid and thionalide (β-aminonaphthalide of thioglycollic acid) are added after partial precipitation by 8-hydroxyquinoline. Should Zn be required, 0.4 mg. of Cd as $CdCl_2$ is added to the original 150 ml. as internal standard. 30 ml. of 2N ammonium acetate is employed initially, followed, after stirring, by 2 ml. of 10% tannic acid in 2N ammonium acetate, 2 ml. of 1% thionalide in glacial acetic acid and immediately thereafter the predetermined equivalent quantity of ammonia to neutralize the acetic acid. This gives the required pH, and after standing overnight, the precipitate, which is free and easily manipulated, is filtered off and ignited at 450° C.

Soil extracts are taken to dryness and, after removal of organic matter by HNO_3, the residue is taken up in hydrochloric acid. Thereafter treatment is similar to that for plant materials. A convenient soil extractant is 2.5% acetic acid, 20 g. of soil being extracted with 800 ml. of solution, but the reagent employed must be governed by the object of the investigation.

The ignited precipitate should normally weigh around 40 mg. Of this 15 mg. are mixed with 30 mg. carbon powder, and part of the mixture filled into the boring of a cathode layer type carbon electrode (boring 1 mm. wide and 8 mm. deep in a 2.8 mm. carbon). It should be noted that carbon and not graphite is employed. Firm, reproducible packing by means of a blunt needle can be achieved with experience and is essential if satisfactory results are to be obtained. This type of electrode gives much more reproducible results than can be obtained with wide shallow borings so often used for arc work. The advantage of carbon over graphite is its lower heat conductivity, giving a hotter cathode and allowing the carbon support to be consumed at the same rate as the sample. Excitation in the cathode enables the tip of the electrode to be included in the field of view of the spectrograph without undue increase in background, and also ensures slow introduction of the sample into the arc gap when this type of electrode is used, thus cutting down errors due to reversal effects. Further details of the method will be found in a number of sources (e.g. Mitchell 1948, 1956).

The electrode burns to the full depth of the boring in a 9 amp. direct current arc (10 mm. electrode separation) in three minutes. The light

reaches the slit of a large dispersion spectrograph (Hilger Large Quartz or similar type) through a 1:2 ratio step sector; a lens at the slit images the arc on the collimator, where a screen masks out light other than from the tip of the cathode and the adjoining one-third of the arc column.

The use of a step sector enables wide concentration ranges to be covered and elements of vastly different line intensities to be determined simultaneously as well as giving a simple plate calibration for each line measured. Photometry follows the variable internal standard method described by Davidson and Mitchell (1940), Fe being used as internal standard after having been determined as described by Scott (1941) in a 10 mg. aliquot of the 40 mg. precipitate. Background correction (Mitchell 1948) is applied when necessary, and evaluation is simplified by the use of Seidel blackening curves (Black 1952). Standard calibration curves are prepared from mixtures of trace elements incorporated into appropriate Al_2O_3-Fe_2O_3 matrixes (Mitchell 1948).

The trace elements which can readily be determined in plant materials, soil extracts and similar biological materials are detailed in Table 1, together with the ranges of contents which can be determined and the wavelengths of the spectral lines employed.

TABLE 1.—Wavelengths and Concentration Ranges for Trace Elements Determined by the Cathode Layer Arc Technique After Chemical Concentration.

Trace Element	Internal Standard	Range in Precipitate	Range in Material Taken (20 g. Sample)
Cr 4254.4	Fe 4250.8	10-3000 p.p.m.	0.02-6 p.p.m.
Co 3453.5	Fe 3451.9	10-3000 p p.m.	0.02-6 p.p.m.
Ni 3414 8	Fe 3413.1	10-3000 p.p.m.	0 02-6 p.p.m.
Zn 3345.0	Cd 3261.1	0.10-10%	2-200 p.p.m.
Ag 3280.7	Fe 3306.4	5-1000 p.p.m.	0.01-2 p.p.m.
Ti 3242 0	Fe 3306.4	30-3000 p.p.m.	0 06-6 p.p.m.
V 3185.4	Fe 3196.9	10-3000 p.p.m.	0.02-6 p.p.m.
Mo 3170.4	Fe 3196.9	10-1000 p.p.m.	0.02-2 p.p m.
Be 3130.4	Fe 3116.6	30-3000 p.p.m.	0.06-6 p.p m.
Ge 3039.1	Fe 3116.6	100-3000 p.p m.	0.2 -6 p.p m.
Ga 2943.6	Fe 2929.0	10-3000 p.p.m.	0.02-6 p.p m.
Sn 2840.0	Fe 2838.1	50-3000 p.p.m.	0.1 -6 p.p.m.
Pb 2833.1	Fe 2838.1	100-3000 p.p.m.	0.2 -6 p.p.m.
Au 2675.9	Fe 2680.5	50-5000 p.p.m.	0.1-10 p.p.m.

There are many statements in the literature to the effect that it is impossible to obtain satisfactory reproducibility by arc emission methods. Our experience has been quite contrary to such assertions, which appear to have been made without adequate practical knowledge of properly executed arc methods. When close attention is paid to the details noted above, it has been found (Mitchell 1956) that a trained non-graduate assistant can obtain results which indicate a coefficient of variation just as good as any other photographically recorded spectrochemical technique. Based on 12 replicates of the same material filled into electrodes at one time and recorded on 2 plates, coefficients of variation of Co 1.4%, V 2.0%, Mo 3.5%, Sn 4.5% and Zn 5.5% were obtained. These values apply to the spectrographic aspect of the method only: the chemical

concentration process may introduce further errors which however cannot be ascribed to deficiencies in the arc technique.

The order of variation which is found for the recovery of trace elements from standard solutions by precipitation with the mixed organic reagents, followed by determination by the cathode layer arc technique described above has been recorded elsewhere (Mitchell & Scott 1948; Nachtrieb 1950). In these recovery tests the errors of individual determinations seldom exceed ±10%, and the coefficients of variation are generally between 5 and 10% with the higher values for the more volatile constituents such as Sn, Pb and Zn, as might be anticipated with arc excitation and as the results previously quoted would suggest.

A recent test in which a soil sample was extracted in 6-fold replication with acetic acid, and cobalt determined in each sample in duplicate electrodes each microphotometer reading being made and reported in duplicate, gave an overall coefficient of variation for a single determination of 3.3%. This figure includes not only the analytical errors but also those involved in drawing 20 g. sub-samples from a bulk supply of soil.

These figures should be sufficient to indicate the reproducibility and, in the solution recovery tests, the accuracy which can be obtained by the technique described, provided the procedure is followed accurately by an experienced worker. We find non-graduate girl assistants, aged 18 years and upwards, can, after a few months training, attain the requisite skill.

A further test of the accuracy of the method is given in Table 2 by the results for Mo and Zn obtained for some different types of plant materials compared with those obtained chemically by Dr. D. Nicholas of Long Ashton Research Station, Bristol. These figures are abstracted from a table in a recent description of the method (Mitchell, 1956). Neither set of values can be accepted as a standard against which to judge the other, but the agreement in nearly all instances between the two entirely different analytical techniques is satisfactory.

TABLE 2.—COMPARISON OF SPECTROGRAPHIC AND CHEMICAL DETERMINATIONS OF MOLYBDENUM AND ZINC IN PLANT MATERIALS, AS PARTS PER MILLION IN DRY MATTER.

	Molybdenum		Zinc	
	Spectrographic	Chemical	Spectrographic	Chemical
Apple Leaves	0 10	0.08	27	—
Pasture Herbage	0.71	0.73	29	26
Wheat Grain	0.05	0.05	42	43
Wheat Straw	0.17	0.16	17	13
Broccoli Leaves	0.10	0 08	53	49
Cauliflower Leaves	0.54	0.50	65	52

The method described above does not provide determinations of Cu or Mn in plant materials, but fortunately these elements are readily determined in plant ash by the method described by Farmer (1950), which differs somewhat from that in Mitchell (1948). In this method about 1 g. of plant material is ashed at 450°C. and 15 mg. of ash mixed with 15 mg. of K_2SO_4 and 30 mg. of carbon powder containing 250

p.p.m. Ag and 150 p.p.m. Cr as internal standards. A somewhat wider carbon electrode is employed in order to introduce more sample and increase sample:carbon ratio, so reducing the chance of errors due to traces of Cu in the electrode material, as well as increasing the sensitivity. Reproducibility is reduced as a consequence and each determination must be arced in duplicate in order to get coefficients of variation around 5%. Otherwise the spectrographic procedure follows that already described. In addition to Cu and Mn, determinations can be made of Ba, Sr, Fe and Mg, while the determination of Al is being examined at present. The small sub-sample required compared with the concentration method results in considerably greater evidence of the effects of local soil contamination being observed in the Fe results. The effect on Cu and Mn contents is however generally insignificant.

The ranges covered by this technique are detailed in Table 3; these cover the contents most frequently encountered in healthy and unhealthy plants. When combined with the concentration technique, a comprehensive survey of the trace element content of plant materials is obtained. We have not so far adopted a spectrographic method for B, although its determination by the porous cup solution spark method has been examined and appears to show promise. Unfortunately all reasonably priced carbons available in Britain contain B and so exclude its simultaneous determination in the plant ash method. In Table 4 will be found some typical results for different types of plant materials from Mitchell (1954).

TABLE 3.—Wavelengths and Concentration Ranges for Trace Elements Determined by Direct Cathode Layer Arc Excitation of Plant Ash.

Analysis Element	Internal Standard	Range in Ash	Range in Dry Matter (10% Ash Basis)
Cu 3274.0	Ag 3280 7	10-3000 p.p.m.	1-300 p.p.m.
Mn 4034.5	Cr 4254.4	30-10000 p.p m.	3-1000 p.p.m.
Fe 3440.6	Cr 3593.5	100-30000 p.p.m.	10 3000 p.p.m.
Ba 4554 0	Cr 4254.4	30-1000 p p.m.	3-100 p.p.m.
Sr 4607.3	Cr 4254.4	30-1000 p p.m.	3-100 p p.m.
Sr 3464.6	Cr 3593.5	1000-10000 p.p.m.	100-1000 p.p.m.
Mg 3336.7	Cr 3593.5	2000-100000 p.p.m.	200-10000 p.p.m.

The concentration technique is applicable, as noted above, to many types of soil extracts, but it is not readily modified for the determination of total trace element contents of soils. The relatively high Fe and Al contents prevent the attainment of a worthwhile degree of concentration. It is, on the other hand, seldom necessary to know the total content of a soil with great precision, as it is the availability of the constituent in question which is really significant. An adequate knowledge of the total reserves in a soil can be obtained from a semi-quantitative estimation which gives values to an accuracy of ±50% of the amount present, and this is readily achieved by a method involving direct arcing of ground soil in admixture with carbon powder, followed by visual comparison of spectral line density with similarly prepared standard plates. But it is rather superfluous to mention this technique here, since Rogers and the other pioneers in this type of work were located in Florida.

TABLE 4.—TYPICAL EXAMPLES OF TRACE ELEMENT ANALYSES OF PLANT MATERIAL EXPRESSED AS PARTS PER MILLION OVEN DRY MATTER.

	Co	Ni	Mo	Fe	Pb	Sn	Zn	V	Ti	Cr	Ag	Cu	Mn	Ba	Sr
Pasture Herbage	0.09	1.3	2.1	75	2.3	<1	30	0.08	3	<0.1	0.04	7.8	120	15	34
Oat Grain	0.05	3.2	0.21	76	1.1	<1	30	0.06	3	0.2	<0.1	1.5	51	4	4
Oat Straw	<0.02	0.16	0.10	26	<0.5	<1	14	0 12	8	0.1	<0.03	1.2	71	31	28
Sugar Beet Leaves	0.29	1.1	0.54	390	3.2	1.5	57	1.3	40	0.9	0.2	10.6	64	11	40
Swede Turnip Tubers	0.06	0.51	0.09	45	<1	<1	19	0.04	2	0.1	<0.06	2.5	6	10	17
Peas (shelled)	0.06	2.3	0.34	65	0.5	<1	72	<0.03	2	<0.1	<0.1	13.7	11	2	2
Tea Leaves	0.07	3.2	0.09	59	<2	<2	37	0.3	13	0.5	<0.2	13.3	640	77	101
Conifer Needles	0.46	2.4	<0.1	162	6.0	<2	42	0.38	23	0.7	<0.2	5.5	520	19	5
Apple Leaves	0.16	2.0	0.14	119	109	2.7	32	1.0	4	0.4	0.08	7.5	34	23	27

A summary of our findings regarding the distribution of trace elements in soils and the effects of pedological processes will be found in Mitchell (1955). Work is at present in progress on trace element aspects of the soil-plant relationship, with particular reference to the effects of fertilizers on trace element uptake, and our results will be published in due course. In this connection, a detailed study is being made of the relationship of plant uptake to the copper content of different soil types, with and without added copper in the soil. It would appear that the soil factors of most significance insofar as trace element availability is concerned are acidity, drainage status and organic matter content. A considerable amount of work has also been done on the cobalt status of Scottish soils in view of the quite widespread distribution of cobalt deficiency in sheep, probably the most important trace element problem in Scotland.

The emission spectrochemical methods which have been developed at the Macaulay Institute are, as already mentioned, not methods which can be introduced quickly into a laboratory and used for a limited period for a specific problem. Rather they are methods which are suitable for long-term research projects involving the examination of a considerable number of samples over an extended period. The initial setting up and calibration of the concentration technique cannot under the most favourable circumstances take less than 3-6 months: the full utilization of the equipment required needs a full-time staff of two qualified workers and several assistants. Spectrochemical methods are not amenable to operation by occasional part-time workers who desire to use them to make a specific analysis in the course of another investigation. This type of work should be passed to a qualified assistant for the actual analysis. In our laboratory, the same assistant carries out the entire examination, from plant material preparation through chemical pretreatment to spectrochemical assessment. Adequate laboratory facilities for the ancillary operations must be available in a form free from the risk of cross contamination from other work. The spectrochemical analysis of biological samples for trace elements cannot be carried out in a few minutes, although, because of the speed with which the simpler analysis of metallurgical samples can be made, this is often expected by those making demands on the facilities. Comprehensive quantitative trace element examination can seldom be made on a routine scale within a week if chemical pretreatment is involved. In a laboratory engaged mainly with plant analysis where, in temperate climates, samples are only available seasonally, a considerable reserve of material for analysis must be kept in order to ensure continuity of employment for the specialist staff; hence delays of several months must be considered normal in such work.

In addition to emission methods, ultraviolet, visible and infrared absorption techniques have been employed at the Macaulay Institute for a number of years to study soil constituents, particularly those of an organic or biological nature, in collaboration with the Departments of Soil Organic Matter and Microbiology. The equipment available includes Beckman DU and Hilger Uvispek spectrophotometers and a Grubb-Parsons Model S4 double beam infrared spectrometer. It is not necessary here to discuss techniques in detail as these generally follow established practice; mention can be made of a few of the lines of work in progress.

The chemical nature of the lignins of sphagnum and other peat forming plants is one investigation which has yielded some results (Farmer

1953, Farmer & Morrison 1955), while the attack of soil fungi on compounds related to lignin has also been studied (Henderson & Farmer 1955). An interesting investigation has been a study of the mode of attack of a soil actinomycete *Nocardia opaca* on fatty materials in the soil (Webley, Duff & Farmer 1955).

Among the organic materials from soils being examined by infrared methods may be mentioned the wax-like materials extracted from soils and peats. Not only organic materials are susceptible to infrared examination. Using the alkali halide pressed disk technique, soil clays and minerals can yield useful information, and exploratory work on these is in progress.

In this short account an attempt has been made to indicate the possible applications of spectrochemical methods to the investigation of soil and plant problems, with illustrations from work actually in progress at the Macaulay Institute. Other workers have developed methods which are equally applicable to their problems, but limitations of space preclude their consideration here.

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CONTRIBUTED PAPERS

Tuesday, November 29, 7:30 P.M.

WALTER REUTHER,* *Chairman*

SOIL SOLUTION SOLUBLE SALTS AS AN INDICATOR OF FERTILITY LEVEL AND NUTRIENT BALANCE

C. M. GERALDSON **

Attempts to correlate results of soil analyses with crop responses and with results of plant tissue analyses have shown that many soil tests are inadequate for use in making recommendations to growers on the sandy soils of Florida. When the value of soil testing was discussed two years ago at the meetings of the Soil Science Society of Florida, similar observations were reported by a majority of the research workers. pH is probably the only test of the many that are run on sandy soils that is widely used for purposes of making recommendations.

During the past 4 years approximately six thousand soil samples have been analyzed. An attempt was made to correlate crop responses where possible with these findings and to utilize data from plant tissue analyses as an aid in the correlations. The measurement and use of soil solution soluble salts as an indicator of general fertility and nutrient balance, appears more and more impressive with the passage of time.

METHODS

For greatest accuracy, soil solution soluble salts (SSSS) should be extracted from the soil at moisture levels approaching field conditions as closely as possible. The labor involved in extracting solutions from soils at field moisture is prohibitive for routine testing. The most feasible moisture content appears to be the saturation extract. The saturation extract is obtained by vacuum filtration of a soil paste that has been made up to a saturated condition by adding water while stirring. About 10 cc of the saturated extract is obtained from a volume of about 75 cc of any soil (sand to muck). The electrical resistance of the saturated soil extract is determined with an Industrial Instruments Conductivity Bride (Model 1B).

Electrical conductivity (EC), which is the reciprocal of the electrical resistance varies directly with soluble salt concentrations. EC readings can be used directly as an indicator of soluble salts(7). EC readings were converted to give an indication of the approximate total soluble salts in ppm by standardizing the instrument with known concentrations of a specific average salt such as KCl. Ppm soil solution soluble salt (SSSS) as reported in this paper has been obtained by the above described

* Head, Department of Horticulture, College of Agriculture, University of Florida, Gainesville.

** Assistant Soils Chemist, Gulf Coast Experiment Station, Bradenton.

procedure. The SSEC is reported as SSSS because soluble salt is generally a more useful common denominator.

Fortunately the saturation percent for most soils is approximately twice the field capacity(7). In Florida this is true for many irrigated sandy soils that have a hardpan 18 to 24 inches below the surface. However, non or infrequently irrigated sandy soils or soils without hardpan would often have a saturation percentage 3 to 4 times the field capacity and these multiples would be used when calculating the soil solution salt concentrations. Consequently measurements made on the saturation extract are simply related to the soil solution at field capacity and the salt dilution effect which occurs in soils because of higher moisture retaining capacity is automatically taken into account. In this paper, field capacities are calculated as half the saturation percentage because the vegetable soils studied contain hardpans and are irrigated.

For purposes of studying nutrient balance the amounts of specific nutrients contained in the saturated extract were determined as ppm and reported as percent of soil solution soluble salt (%/SSSS). Generally 5 to 10 cc of the saturation extract was made up to 50 cc in a volumetric flask. Nutrients and other ions commonly contained in the soil solution, such as calcium, magnesium, potassium, sodium, phosphorus, chloride and nitrate and ammonium nitrogen were determined from aliquots of this diluted saturation extract; minor elements were determined from undiluted portions of the extract.

To study the nutrient balance (calcium particularly) in unfertilized soils, 25 cc of the soluble portion of a 4-8-8 fertilizer (4 gms./liter) was added to soil samples and extraction and procedure from then on was identical to those soils which had been fertilized previous to sampling.

FERTILITY LEVELS

Magistad et al(5) state that best growth of plants was obtained when the soil solution osmotic pressure was maintained between 0.3 to 2.0 atmospheres. Roughly this would be equivalent to about 600 to 4000 ppm total soluble salts. Soils that are not heavily fertilized or those that supply liberal amounts of nutrients from the exchange complex generally contain only small amounts of soluble salts (200-1000 ppm) in the soil solutions. Sandy soils in Florida used in growing vegetable crops generally contain from 400 to 10,000 ppm total salts in the soil solution.

It is possible that a minimum and maximum and possible optimum soil solution soluble salt concentration could be determined for crop and soil if sufficient correlations were carried out.

During the 1953-54 season, soils from tomato fields in the Manatee-Ruskin area were periodically sampled and tested. Average soluble salt content of these samples, associated amounts of fertilizer used and resultant yields are presented in Table 1. From these results it would appear that an inadequate fertility level was maintained especially toward the end of the season (Fall crop especially) when crop requirement is considered to be a maximum.

In Table 2 results of similar analyses are presented for certain individual fields. Standard fertilizer recommendations do not sufficiently take into account variations in soil nutrient supply and plant requirement.

The soil solution soluble salt test serves as an indicator of the fertility level—a summation resultant of all the contributory factors. Irrigation water, organic matter, and fertilizers supply soluble salts to the soil and the plant and leaching remove salts from the soil. Results to date indicate that with tomatoes the soluble salt level for best results should be maintained between 2000 and 4000 ppm with levels increasing as the season progresses.

TABLE 1.—AVERAGE SOIL SOLUTION SOLUBLE SALT LEVELS, FERTILIZER USED, AND TOMATO YIELDS.

	PPM SSSS at Various States of Maturity				Fertilizer (4-8-8 Equiv.) Lbs./A.	Yield Marketbale Fruit Bu./A.
	Young Plant	Fruiting	Picking	Average		
Fall (average 31 fields)*	1960	2016	860	1612	3900	205
Spring (28 fields)	2107	2020	1830	1986	3000	275

* Twenty-nine inches of rain was recorded for the fall crop season. Leaching was not a factor during the spring crop season.

An explanation of results presented in Table 2 is as follows: Field 1 had a good cover crop and received a recommended amount of fertilizer. Field 2 had a poor cover crop and inadequate fertilizer. According to recommendations field 3 and 4 received an excessive amount of fertilizer. The fact that field 4 has a very poor moisture and nutrient-retaining capacity and also received overhead irrigation accounts for the results. Field 3 was subirrigated (tile). It is believed that the relatively high level of fertility at harvest time (Field 3) is important for optimum yields and quality.

TABLE 2.—COMPARISON OF SOIL SOLUTION SOLUBLE SALTS, FERTILIZER USED, AND TOMATO YIELDS.

Field	PPM SSSS at Various Stages of Maturity				Fertilizer (4 8-8 Equiv.) Lbs./A.	Yield Marketable Fruit Bu./A.
	Young Plant	Fruiting	Picking	Average		
1. Ruskin	3300	2860	2090	2750	2750	330
2. Ruskin	610	1240	1320	1060	1925	180
3. Gulf Coast Expt. Sta.	2700	3630	4000	3410	5400	750
4. Gulf Coast Expt. Sta.	600	1080	400	690	4500	155

The reduction of yields due to excessive amounts of soluble salt is also an important consideration. Accumulation of salts from fertilizer or irrigation water is a primary source of excessive soluble salts in Florida soils.

The U. S. Salinity Laboratory at Riverside. California, has made a comprehensive study of salt tolerances of a number of crop plants. Some of their results concerning certain vegetables are presented in Table 3.

TABLE 3.—Relative Tolerance of Vegetable Crops to Salt(7)*.

High Salt Tolerance	Medium Salt Tolerance	Low Salt Tolerance
ECe x 10^3 = 12 (16800 ppm)	ECe x 10^3 = 10 (14000 ppm)	ECe x 10^3 = 4 (5600 ppm)
Garden beets	Tomato	Radish
Asparagus	Cabbage	Celery
Spinach	Pepper	Green beans (4750 ppm)
	Cauliflower	
	Lettuce	
	Sweet corn	
	Potatoes (8700 ppm)	
	Carrots	
	Onion	
	Squash	
	Cucumber	
ECe x 10^3 = 10 (14000 ppm)	ECe x 10^3 = 4 (5600 ppm)	ECe x 10^3 = 3 (4200 ppm)

* The numbers following ECe x 10^3 are electrical conductivity values of the saturation extract in millimohs per cm at 25° C. associated with a 50 percent decrease in yield. Crops are listed in order according to decreasing salt tolerance. Millimohs per cm. multiplied by 1400 give the approximate ppm soluble salts (calculated using a KCl standard) in the soil solution at field capacity and are the figures in parenthesis. It should be remembered that yield reductions begin at much lower concentrations than that associated with a 50 percent yield decrease.

Excess soluble salts reduce yields by limiting moisture available to the plants (high osmotic pressures). This can often be a hidden source of reduced yields as no specific symptoms are evident. Plants may appear darker green in color and maintain a slower rate of growth. A smaller, less vigorous plant resulting in yield reductions of 10 to 20 percent would never be noticed by the average grower. Quality generally is not adversely affected unless the nutrient balance is upset by an excess of certain cations or anions. This will be discussed further under the section on "nutrient balance".

As soluble salt concentrations increase, the relative activities of the divalent salts decrease at a more rapid rate than the monovalent. Relative activities of certain salts at 3 concentrations are presented in Table 4. Such an effect would tend to limit magnesium and especially calcium uptake by plants from high salt solutions even though calcium salts remained proportionately the same as concentrations increased. As relative activities of a cation decrease, the associated bonding energies for uptake of that cation by the plant increase which results in decreased uptake of that cation(6).

Blackheart, a physiological disorder of celery associated with a calcium deficiency and controlled with calcium sprays, has occurred frequently where soil solution soluble salts have been excessive(2). Blossom-end

rot of tomato and pepper, also physiological disorders associated with a calcium deficiency, can similarly be caused by high salt concentrations(4).

TABLE 4.—Relative Activities at 3 Concentrations of a Number of Salts Commonly Found in the Soil Solution(1).

Concentration	NaCl	KCl	$Ca(HCO_3)_2$*	$CaCl_2$	$CaNO_3$	K_2SO_4	$MgSO_4$	$CaSO_4$*
0.01M	.903	.902		.732		.690	.400	
0.05	.811	.817		.584		.505	.225	
0.10	.778	.769		.531	.480	.421	.150	

* Salts included to indicate relative position.

NUTRIENT BALANCE

An unbalanced ratio as well as deficiencies and excesses of specific nutrients in the substrate solution can cause abnormal growth of plants and such abnormalities must be detected and eliminated before the SSSS can be successfully correlated with crop response. In this study attempts were made to correlate plant responses with ratios, deficiencies or excesses of cations and anions found in the soil solution. Deficiency or toxicity symptoms, abnormal growth, tissue analyses as well as yields and quality were used as indicators of response.

Most of the current investigation thus far has centered around calcium, believed to be one of the key nutrients in nutritional balance because of its immobility within the plant. For all practical purposes calcium is not translocated from older to younger plant tissue. Thus even a temporary deficiency or imbalance which might retard calcium uptake may be reflected by plant response.

Florida soils often contain inadequate supplies of calcium. Virgin sandy flatwood soils commonly have a pH of 4.5 or lower. Most of these soils contain varying amounts of a natural source of calcium such as marl or shell in the subsoil. The standard practice is to supply two or three tons of liming material per acre 6 inches. This usually raises the pH of the plow layer above 5.5. A soil test will generally show that the "available calcium" has been increased accordingly. Despite the above practices many cases of probable calcium deficiencies have occurred indicating that the pH and "available calcium" tests are not always adequate as indicators of the calcium-supplying capacity of the soil. The term, calcium-supplying capacity, refers to the calcium a plant might obtain from the entire root zone.

The percent calcium contained in the soil solution soluble salts has been found to be an excellent indicator of the calcium-supplying capacity of a soil. Softness in tomato fruits which often causes poor carrying quality has been associated with a calcium deficiency(3). Results illustrating this point are presented in Table 5. Best quality and yields resulted when the SSSS contained 20 percent or more calcium. pH or "available calcium" as commonly determined do not necessarily correlate with the percent Ca/SSSS or plant response.

TABLE 5.—CORRELATION OF QUALITY AND YIELD OF TOMATOES FROM 18 RUSKIN FIELDS (FALL 1953) pH AND WITH PERCENT CA/SSSS.

Quality*	Number of Fields	Yield Bu./A.	pH	% Ca/SSSS Average	% Ca/SSSS Final
Best 1	3	250	5.9	30.5	28.5
2	9	260	5.5	23.5	24.1
3	3	140	4.9	13.5	14.1
Poorest 4	3	200	5.7	16.6	10.8

* The number 3 and 4 quality tomatoes broke down in shipment.

The prevalence and severity of blossom-end rot, a physiological disorder of tomatoes, has been found to vary inversely with the Ca/SSSS percent. A successful control method for blossom-end rot includes a program for maintenance of 20 percent or more calcium in the SSSS. Supplementary calcium sprays can be used if the Ca/SSSS is at any time considered inadequate for plant needs. Results of a soil pot culture experiment(4) are presented in condensed form in Table 6. It is obvious that the total ppm calcium in soil solution is not correlated with the production of blossom-end rot, but these same figures when calculated as % Ca/SSSS do correlate with the prevalence and severity of the disorder. In this experiment the movement of fertilizer salts bearing competitive cations into the root zone seems to be the important factor in the production of blossom-end rot. Moisture levels and variations have often been associated with the disorder.

TABLE 6.—CORRELATION OF BLOSSOM-END ROT OF TOMATOES WITH PERCENT CA/SSSS AS AFFECTED BY LIMING MATERIAL, FERTILIZER AND MOISTURE APPLICATION.*

Lime Source	pH Average	Before Application of Fertilizer: Sol. Salt ppm	Before: Soil Sol. Ca ppm	Before: Soil Sol. Ca %	Before: BER	After Appli. of 1000 lbs. 4-8-8-/A: Sol. Salt ppm	After: Soil Sol. Ca ppm	After: Soil Sol. Ca %	BER (%)
1. 6000 lbs. Dolomite	5.2	1540	286	16.6	0	3140	398	12.7	21.8
2. 3000 lbs. Dolomite + 3000 lbs. Agric. lime	5.5	1580	316	20.0	0	3600	482	13.1	25.0
3. 6000 lbs. Agric. lime	5.6	980	236	24.2	0	2280	400	17.6	11.5
4. Same as (2) + 2000 lbs. gypsum	5.2	1460	414	28.4	0	3400	748	22.0	2.3

* Figures given are averages of 4 replications. Water was applied daily to plants maintaining rapid growth in sandy soil contained in 4 gallon crocks. No blossom-end rot was produced although moisture levels fluctuated greatly, until fertilizer (plus water to leach it into the root zone) was applied. Blossom-end rot then developed within 24 hours.

Experimental evidence also indicates that low Ca/SSSS percentages are associated with the occurrence of blackheart of celery and blossom-end rot of peppers. Unpublished data of a preliminary nature indicates that size of tomato fruit is directly correlated with calcium supplying capacity of a soil.

DISCUSSION

Many paired leaf and soil samples have been analyzed from tomato fields in various parts of the state. If the SSSS contains, consistently during the growing season, 20 percent or more calcium, the associated leaf sample will usually contain from 1.5 to 2.5 percent calcium. If the soil test consistently indicates 10 to 15 percent calcium, the associated leaf sample will usually contain around 1 percent calcium.

A temporary calcium deficiency as indicated by a corresponding lower % Ca/SSSS will not necessarily show up in a leaf analysis. However, the temporary deficiency will cause physiological disorders which can be directly correlated with factors that caused the temporary reduction of Ca/SSSS. Poorer quality of tomato fruit(3), incidence of blossom-end rot(4), and the prevalence and severity of blackheart of celery(2) are often associated with a low percent Ca/SSSS or factors which lower the Ca/SSSS, but not necessarily correlated with a low calcium content in the leaf.

Results presented in Tables 5 and 6 are typical of the variation in the calcium-supplying capacity of soil solutions and also exemplify some of the factors causing the variation. Unlimed virgin soils have been found to contain from 3 to 20 percent Ca/SSSS depending on the amount, depth, and source of calcium-bearing materials. When liming materials containing magnesium are applied, less calcium as well as greater amounts of a competitive cation are supplied per unit of liming material. This is most important in soils that have a naturally poor calcium-supplying capacity.

Fertilizer containing potassium, ammonium, sodium and magnesium supply cations which reduce the percent Ca/SSSS. Nitrogen becomes a special problem because it can exist as a cation or anion and excesses of either can accentuate a calcium deficiency(4). Nitrogen levels and nitrate/ammonium ratios can vary with the amount and rate of breakdown of organic matter as well as with the amount added in fertilizers. The nitrate/ammonium ratio also varies with the pH and moisture level. The movement of salts in and out of the root zone by rainfall or irrigation water is of primary importance in these considerations. Consistently wet soil will favor an accumulation of ammonium while a dry soil tends to concentrate existing quantities of soluble salts which by a different mechanism previously described retards calcium uptake by the plant.

It is recognized that certain cations will furnish more competition to calcium uptake than will equivalent amounts of others. Such variations must be considered when evaluating the Ca/SSSS percent with the objective of making recommendations.

Separate samples are often analyzed to check the subsoil source of calcium as an important part of the total calcium-supplying capacity of a soil. The importance of sub-soil calcium would vary with the amount of root development in the subsoil. The calcium-supplying potential of

the subsoil of cultivated soils generally increases with time if liming material is periodically added and a source of calcium such as superphosphate is contained in the fertilizers. Downward movement can also cause a loss of soluble calcium salts in leachate runoff.

The above discussion of the various factors that affect the calcium-supplying capacity of a soil does not include the plant requirement. The rate of plant growth and a variable metabolic activity as it affects calcium requirement are also important factors to consider when determining if the calcium-supplying capacity of a soil is adequate(2, 4).

Calcium is considered a key element in nutritional balance and has been the predominant topic of discussion in this paper. It is believed that other cations or anions might be similarly studied with possible useful results. Besides excessive amounts of specific cations as they might reduce percent Ca/SSSS, high percent chloride/SSSS has been associated with poor quality and lower yields of certain crops.

SUMMARY

The soil solution soluble salts (SSSS) are determined from the saturation extract of the soil. The total soluble salts contained in the soil solution are the summation resultant of soluble salts supplied to the soil by irrigation water, fertilizers, and breakdown of organic matter, and those removed from the soil by plants and leaching. Minimum, maximum and perhaps optimum levels of SSSS that should be maintained can be determined for best yields and quality of specific vegetable crops. Excess soluble salts have been associated with a calcium deficiency causing blackheart of celery and blossom-end rot of tomato and pepper as well as general yield reductions of many crops not being able to obtain adequate water from solutions having high osmotic pressures.

A grower using this method as a guide can maintain a fertility level which has been associated with maximum yields and quality. An unbalanced ratio as well as a deficiency or excess of specific cations or anions obviously cannot be detected by measuring total salts and such abnormalities must be eliminated before the SSSS can be successfully correlated with crop response.

Specific cations or anions contained in the saturation extract are determined and reported as percent of the SSSS. In this manner a study of nutritional balance, which has clearly shown calcium to be a key nutrient, was undertaken. The percent calcium contained in the soil solution soluble salts (percent Ca/SSSS) has proven very useful as an indicator of calcium-supplying capacity of a soil. Poorest quality tomatoes, incidence of blossom-end rot of tomatoes and of blackheart of celery were associated with a low Ca/SSSS or factors which cause a low Ca/SSSS, but not necessarily associated with a low calcium content in the plant tissue. Calcium deficiencies of a temporary nature generally are not indicated by leaf analysis, but the above-mentioned plant responses and the associated reduction in percent Ca/SSSS can occur as the result of a temporary as well as a more persistent calcium deficiency.

The percent Ca/SSSS can be increased by additions to the soil solution of the more soluble calcium-bearing materials and can be decreased by additions to the soil solution of cations such as magnesium, ammonium, potassium and sodium. These cations on an equivalent basis are not

equally competitive to calcium which must be considered when making recommendations. High or low moisture levels and movement of competitive cations into the root zone by moisture adversely affect the calcium uptake by the plant. The calcium-supplying capacity of many Florida soils is less than 20 percent Ca/SSSS. For the tomato crop, a 20 percent level (Ca/SSSS) has been arbitrarily chosen as desirable and necessary to avoid troubles associated with lower calcium levels.

Interpretation of the percent Ca/SSSS test for purposes of making recommendations must be influenced by some of the above mentioned contributory factors as well as rate of plant growth and metabolic activities which may upset the balance between plant requirement and soil supply.

The effectiveness of the soil solution soluble salt test in indicating fertility levels and calcium-supplying capacities that apply to and explain crop responses observed with tomatoes suggests that similar tests can be helpful with many other crops.

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RELATIONSHIP BETWEEN DEPTH TO HEAVY-TEXTURED SUBSOIL AND DROUGHT INJURY TO PECANS

Nathan Gammon, Jr., Ralph H. Sharpe and Ralph G. Leighty *

The 1954 pecan crop in Florida was extremely light, but growing conditions in the northern peninsular area were satisfactory and a very heavy nut crop was set in the spring of 1955. However, the rainfall for 1954 in this area was about 26 percent below normal. It continued to be below normal at about the same percentage through the winter and spring of 1955. Severe drought conditions were encountered during May and early June. There was a modest shedding of nuts in May that was attributed to the continued dry weather.

Between the 1st and 15th of June, an unusually heavy shedding of nuts by Curtis and some other varieties was observed. In some groves all trees were affected, in others the shedding was spotty with trees with full crops as close as 50 to 150 feet from trees that had shed every nut. The depth to a heavy-textured subsoil in these groves was observed to be an important factor in this variability in shedding. No evidence of disease or insect damage was observed. It is the purpose of this report to show that when the heavy-textured layer in these soils was near the surface, the area of root growth was limited and the trees were, therefore, more susceptible to drought.

Blackmon(1) recommended that pecans be planted on deep, well drained soils for best results and stated that soil drainage was more important than air drainage (frost protection). Hunter(3) reporting on the severe drought conditions in Georgia in 1954, stated that trees on the deep, sandy soils such as Norfolk and Orangeburg series withstood the drought much better than those on Tifton, Ruston and Greenville series. His opinion was that pecans did not root extensively in the heavier-textured subsoils and consequently had a more limited volume of soil from which they could obtain moisture.

Reports of heavy, but very localized, shedding of nuts were received from many of the pecan growing areas in Florida in 1955. However, the data reported here are from Alachua and Bradford Counties where the Curtis variety is planted quite extensively.

Pecans are planted largely on the Rex, Blanton and Lakeland series in these counties. The Rex soils are characterized as being from moderately well to somewhat poorly drained. The surface soils are sands and loamy sands and have subsoils of sandy clay or sandy clay loam at depths of 18 to 30 inches. In the thin-surface phase the heavy-textured materials may occur within 18 inches of the surface. The Blanton soils are moderately well to well drained soils, while the Lakeland is a well to excessively drained soil. The modals for these soil series have sands

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* Soils Chemist, Associate Horticulturist and Associate Soil Surveyor, respectively, Florida Agricultural Experiment Station, Gainesville, Florida.

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to depths greater than 42 inches, and shallow phases occur when the heavy-textured material begins at 30 to 42 inches. The Rex and Blanton soils regularly exhibit mottling in the heavy-textured layer, a sign of relatively poor internal drainage and lack of aeration. This mottling was consistently encountered in the clays reported at depths of less than 40 inches in this paper. Although these soils do differ in minor ways in some other characteristics(2), the depth to clay [1] and degree of drainage are the important ones to be considered here. These soils are frequently associated in this area and it is not uncommon to find all three within a single small pecan grove.

The effects of drought and depths to the heavy-textured soil layer on the yield of Curtis pecans is clearly shown in Table 1. The exact depth to the heavy layer is not an absolute measure of the drought damage, since it is recognized that the heavy-textured layer varies widely itself and may influence root penetration. Also, the local rainfall pattern will influence the degree of damage as, for example, at least one inch more of rain is known to have fallen at the Earleton farm than at the Orange Heights farm the last week in May. Hence the crop loss was more severe at the corresponding depths to the heavy-textured layer at Orange Heights.

TABLE 1.—EFFECT OF DEPTH TO HEAVY-TEXTURED SOIL LAYER ON CURTIS PECAN CROP UNDER DROUGHT CONDITIONS. SEPTEMBER 20, 1955.

Farm Location	Depth to Heavy Texture	Crop*	Notes
Melrose, Florida	22″	0	Two trees.
Melrose, Florida	29″	¾	60 feet from above trees.
Melrose, Florida	34″	1	60 feet from above trees.
Melrose, Florida	24″	Trace	Near swamp.
Melrose, Florida	38″	1	120 feet from above trees.
Orange Heights, Florida	24″-28″	0	Consistent variation and
Orange Heights, Florida	30″-32″	¾	growth response over
Orange Heights, Florida	42″+	1	16 acre grove (270 trees).
Earleton, Florida	20″	0	Extreme differences
Earleton, Florida	24″	¼	found within 200 feet
Earleton, Florida	36″-42″	1	(170 trees).

* Figure 1 indicates full crop.

It is probable, as observed by Hunter(3), that the mottled heavy-textured layer restricts root growth and hence under drought conditions the tree roots are limited to the reserve moisture stored in the soil horizons above the clay. Observations of small and large trees growing on soils which had the same depth to a heavy-textured layer, indicate that this limited soil volume becomes more critical as the trees increase in size and the tree moisture requirements increase correspondingly. Under Florida conditions a temporary water table may stand for extended periods of time at about the same level as the clay in the Rex soil and for shorter

[1] Clay used in this sense refers to heavy-textured material ranging from sandy clay loams to clays.

periods in the Blanton and Lakeland. The presence of this water table may inhibit or actually "kill back" roots that penetrate to these depths. This is also the cause for the development of the mottling in this layer.

Pecans are normally deep rooted trees and they usually break up badly rather than blow over. Yet a pecan tree over two feet in diameter, growing on a Rex soil with sandy clay loam within 20 inches of the surface, was blown over during the summer of 1955. Examination of the exposed roots showed that none had penetrated the soil more than 20 inches.

That water was the important factor in retention of nuts is clearly shown by the responses obtained in two groves that were partially irrigated. A 60-acre grove near Waldo, depth to clay 28 inches, was partially intercropped to vegetables and irrigation was used for the vegetables. When the extremely dry weather set in, irrigation was extended to as much of the grove as could be covered with the available equipment. All trees that were irrigated retained a crop large enough to cause limb breakage, while non-irrigated Curtis trees shed all of their nuts and other varieties retained only a light crop. A 40-acre grove near Starke, depth to clay 24 inches, was irrigated by gravity flow ditches and the trees that could not be reached by this system lost their entire crop, while the irrigated trees produced a heavy crop.

The data reported here are for the Curtis variety because the effect was so striking and because of the large number of trees of that variety planted in the area. Some other varieties also shed most of their nuts under these conditions. Zinc (Big Z) and Schley were among the hardest hit. However, Kennedy, supposedly developed from the same genetic stock as Curtis(1), proved to be extremely resistant to the drought conditions. In many groves, Kennedy trees were observed with a full crop of nuts, while surrounding Curtis trees were barren. Borings revealed no soil differences in these cases. Many seedling trees also appeared extremely resistant.

Several years ago the authors made extensive studies of the soil around pecan trees on which individual yield records had been kept. The trees were paired on the basis of high and low yields. Of the many measurements, taken, only two were of any significance. The low yielding trees had larger trunk diameters and the depth to a heavy-textured layer averaged three and one-half inches less than for the high yielding trees. These same water shortages may have recurred frequently but less acutely during the normally dry spring seasons, resulting in some shedding of nuts on the shallower soils. When this was followed by a normal water supply during the summer, a larger tree growth occurred because of the lighter nut crop.

CONCLUSIONS

For maximum drought resistance, pecans should be planted on soils with 42 inches or more of well-drained light-textured material in the surface. Planting on soils with less than 36 inches of well-drained light-textured material in the surface should be avoided if possible, since severe drought injury may be effected in some seasons. Pecan roots evidently do not penetrate poorly drained or mottled heavy-textured soil horizons.

The Curtis and Zinc varieties were particularly susceptible to these drought conditions, while the Kennedy was most resistant. Further evaluation of these factors could be important in selecting pecan varieties to be grown on marginal soils.

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VIRUS DISEASES OF LUPINES IN FLORIDA

M. K. Corbett *

Lupines have been used as a cover or green manure crop in Europe, Australia and New Zealand for many years. During the past fifteen years, lupines have become rather extensively grown in an area of the United States comprising Northern Florida, Southern Alabama and Southern Georgia as a cover or green manure crop. Bitter blue, a high-alkaloid-content lupine (*Lupinus angustifolius* L.) has been satisfactorily used in this area as a green manure crop. The recent trend has been to the use of either sweet selections of blue lupine or sweet selections of yellow lupine (*Lupinus luteus* L.) for a forage and seed production crop. The production of yellow lupine has been greatly hindered by a virus disease which reduces green weight per acre and may cause a failure in seed production.

The United States Department of Agriculture, Bureau of Agricultural Economics, showed that the acreage of lupines grown for seed production in Florida decreased between 1950 and 1954. In 1950; 130,000 acres were planted, of which 16,000 acres were harvested for seed. These yielded 650 lbs. per acre, with a production value of 510,000 dollars. In 1954; 120,000 acres were planted of which only 7,000 were harvested, yielding 500 pounds per acre with a production value of 172,000 dollars. This reduction in acres harvested for seed may be due, in part, to the devastating nature of the virus upon seed set.

Neill et al. in 1934(7) described a disease of blue lupines in New Zealand which they termed "sore-shin" and attributed its cause to a virus. Chamberlain(1) working with the same disease transmitted the virus to garden peas which developed a mosaic. He then recovered the virus to blue lupines which developed typical symptoms of the "sore-shin" disease. Thus, he concluded the "sore-shin" disease of blue lupines was caused by the pea mosaic virus. The virus was not transmitted by *Thrips tabaci*, but was readily transmitted from infected broad beans and peas by two species of aphids; *Myzus persicae* and *Aphis rumicis*. Chamberlain(1) obtained no evidence for transmission of the virus through the seed of infected plants.

Kohler(6) reported a virus disease of lupines from Germany. The symptoms were not identical with the "sore-shin" disease of blue lupines in New Zealand. Kohler termed the disease "lupine browning" and attributed its cause to cucumber mosaic virus. Richter(9) presented additional evidence concerning the identity of the virus, and showed that the alternate hosts of the virus were several common weeds. Chamberlain(2) also reported cucumber mosaic virus as a possible disease of lupines in New Zealand.

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* Assistant Plant Pathologist, Agr. Exp. Sta., Gainesville, Florida. Grateful acknowledgment is made to Erdman West for plant identification, to Dr. A. N. Tissot for identification of the aphid species and to Dr. A. A. Cook for preparation of the photographs.

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Norris(8) reported from Australia that pea mosaic virus was the causal agent of a disease tremed "bunchy top" of *Lupinus varius* and the "sore-shin" disease of *L. angustifolius*. The virus was mechanically transmissible to peas, broad beans, subterranean clover, red clover and several lupine species. Nine species of aphids were collected and all were able to transmit the virus. The common perennial garden shrub *Cassia corymbosa* was reported to be the alternate host of the virus during the hot, dry summers.

Decker(3) in 1950 reported a sap-transmissible disease of apparently virus origin in yellow lupines. This disease was observed later that year in the plantings of sweet and bitter blue lupines at Gainesville, Quincy and Jay, Florida. He observed that the disease markedly reduced the plant growth and seed set.

Weimer(10) reported two virus diseases of blue lupines in Georgia; one at Tifton and the other at Oglethorpe. He described the diseases as being in epiphytotic form. The Tifton virus caused dwarfing and curling of the leaves with proliferation of the axillary buds. The Oglethorpe virus caused dwarfing of the leaflets but the leaves were wider and thicker and pointed upward rather than curling downward. Both diseases caused dwarfing, malformation and ultimately death of the plant. Weimer(10) reports that the causal agent of the Tifton disease could be mechanically and aphid transmitted from blue lupine to blue lupine, pepper, cucumber and possibly Dixie Wonder field peas. The disease appeared in severe form when the plots were near Dixie Wonder field peas, but did not appear when peas were omitted from the rotation. He suggests from this field evidence that possibly the disease was caused by the pea mosaic virus or some other virus disease of peas.

Klesser(5) reports five virus diseases of lupines in South Africa. Each virus was differentiated on the symptoms produced in the three lupine species, blue, yellow and white (*Lupinus albus*). All five viruses were aphid transmitted. The symptom picture described could include all the virus diseases thus far reported from lupines.

Lupines grown at Gainesville, Quincy and Live Oak, Florida; Moultrie, Lakeland and Tifton, Georgia, this past year exhibited various symptoms of virus infection. Preliminary work by the author indicates that a single virus tentatively designated lupine virus number one causes most of the damage. Lupine virus No. 1 induces three distinct sets of symptoms in the three lupine species grown in this area as agronomic crops. In the blue lupine (*Lupinus angustifolius*) the disease is very similar to that termed "sore-shin" in New Zealand and Australia. The disease is characterized at an early stage of infection by a slight bronzing and wilting of the foliage. At a later stage of infection (Fig. 1), the foliage turns a deeper bronze, leaves start to drop and necrotic stem streaks develop. The stem becomes necrotic and the growing point or apex of the plant bends to the side of the necrosis. The plant eventually dies. This symptom may be caused by other factors but in general it may be attributed to virus infection and has been termed shepherds crook.

Early stages of infection in the yellow lupine are characterized by vein-clearing which develops into a light mottle with leaf narrowing and deformation. This condition progresses (Fig. 2) to a severe stunting of the plant with abortion of flowers and seed pods. Late season infection

will result in the older leaves of the plant appearing healthy and normal with only the newer growth exhibiting leaf mottling and deformation.

White lupines at an early stage of infection may exhibit leaf vein-clearing which develops into a severe mottle with various leaf deformations and flower abortion.

Figure 1. Blue lupine (*Lupinus angustifolius*) infected with lupine virus No. 1.

Figure 2. Yellow lupine (*Lupinus luteus*) infected with lupine virus No. 1.

A second virus, tentatively designated lupine virus number two, causes in blue lupines symptoms different from that already described. Infection by this virus is characterized by a proliferation of the leaf axillaries with narrowing, rolling and deformation of the leaves (Fig. 3). This virus does not result in death of the infected plant. Symptoms resulting from infection by this virus in the yellow and white lupines are identical with those already described for lupine virus No. 1. Any of the above described symptoms may vary depending upon time of infection in relation to plant growth and temperature.

Blue and yellow lupines may exhibit in the field a symptom referred to as "little leaf" or "mouse ear" (Fig. 4). The upper leaves of the

affected plants are very small, thick and numerous. Affected plants develop a very bunchy appearance. The causal agent for this disease has, at present, not been experimentally transmitted.

Figure 3. Blue lupine (*L. angustifolius*) infected with lupine virus No. 2.

Figure 4. Blue lupine (*L. angustifolius*) exhibiting symptoms of "little leaf" or "mouse ear".

Cucumber mosaic virus (*Marmor cucumeris* H.) has not been isolated from field grown diseased lupines. Experimentally it causes a disease in lupines differing from that seen in the field this last year. Blue lupines infected with cucumber mosaic virus exhibit symptoms of stunting, leaf proliferation, and curling, giving the plant a bunchy appearance. Some leaves curl so tightly that they give the appearance of ball-like structures. The stems turn brown and slightly necrotic. The entire symptom picture resembles that reported by Weimer(10) for the Tifton virus.

Experimentally the host range of lupine viruses No. 1 and No. 2 have been limited to the family Leguminosae. Twenty-three species of nine non-leguminous families have been tested by the carborundum gauze-pad method of mechanical inoculation. All non-leguminous plants tested were immune to infection by both viruses. Thirty-two species of twenty genera of the family Leguminosae have been tested with both viruses and 19 were susceptible. In all cases, recovery of the virus was attempted from the non-inoculated leaves of the test plants. Among those legumes growing in Florida which are susceptible to both viruses are: *Crotalaria spectabilis* Roth.; *Lathyrus odoratus* L. (sweet pea); *Lespedeza striata*

(Thunb.) Hook. & Arn.; *Melilotus alba* Desr. (white sweet clover); *M. indica* (L.) All. (yellow sweet clover); *Mucuna deeringiana* (Bort.) Merr. (velvet bean); *Ornithopus sativus* Link (serradella); *Phaseolus vulgaris* L. (bean, eight varieties tested); *Pisum sativum* L. (English pea, seven varieties tested); *Trifolium pratense* L. (red clover); *Vicia faba* L. (broad bean); and *V. sativa* L. (common vetch).

Lupine virus No. 1 was recovered from naturally infected white and yellow sweet clovers growing in the vicinity of lupine fields. These two plants could well serve as a perennial source of the virus in Northern Florida where they grow the year around.

Both lupine viruses No. 1 and No. 2 are transmitted by at least two species of aphids. Aphids, *Myzus persicae* (Sulzer) and *Aphis medicaginis* Koch, collected from lupine fields in Florida and Georgia transmit both viruses to all three lupine species. From preliminary work with lupine virus No. 1, the efficiency of the insect vector depends upon the source of the virus and the test plant used. Tests using single aphids *Myzus persicae* with a 2-4 hour pre-acquisition starving followed by a 15-20 second acquisition feeding transmitted the virus to thirteen of twenty white lupine plants tested. The per cent transmission is less if blue lupine is used as the source plant. This may be attributed, in part, to virus concentration in the source plant due to the necrotic reaction of the virus on the plant, or to the palatability of the source plant to the insect vector.

Decker(4) reported that the virus is seed-borne in yellow lupine. Yellow lupine infected with the virus does not die but remains as a reservoir of inoculum in the lupine field. Lupine virus No. 1 is lethal in the blue lupine, thus infection by this virus kills the plant and removes them as a potential source of inoculum.

Control of the virus diseases of lupine, although still in the experimental stage, may be practiced in several ways. First, the use of disease-free seed; second, control of the insect vectors; and third, the eradication of the virus source in the weeds. The practice of disease-free seed and weed control should help give a better yield of green weight and seed per acre.

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FERTILIZER CONSUMPTION IN FLORIDA

William L. Pritchett*

Florida's sandy soils are inherently infertile in their virgin state; however, in spite of this fact they are highly productive when properly managed. Since these light soils have a low plant food reserve, Florida farmers have long realized the importance of adequate fertilization in a good management program. The continued marked increase in consumption of both fertilizer and liming materials illustrates the farmers' faith "that tillers of soils of low native fertility need no longer be held down to a standard of living based on nutrient delivery of low producing fields". Certainly they have the production capacity and enjoy a standard of living often surpassing their neighbors on better land.

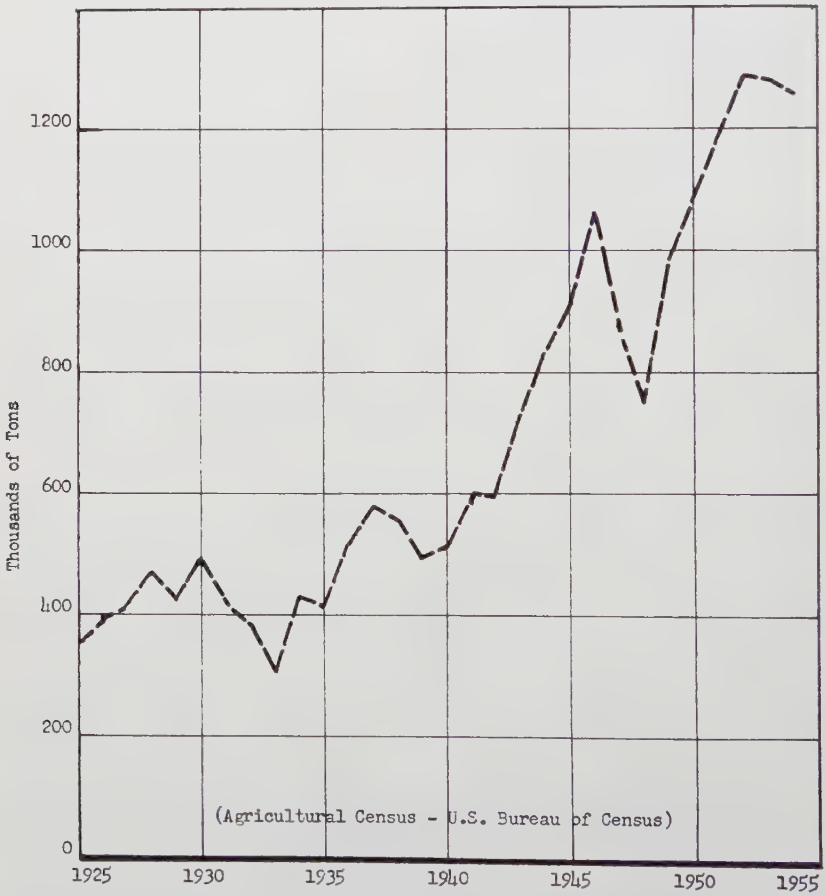

Figure 1. Fertilizer consumption in Florida.

* Soil Technologist, Agricultural Experiment Station, Gainesville.

The Florida farmer applies the highest per acre rates of fertilizer in the nation.[1] His average annual application of commercial fertilizer to cultivated land was reported to have been 1440 pounds in 1953. This was more than twice the average applications of 625, 608, and 589 pounds applied by farmers of New Jersey, Rhode Island and North Carolina, respectively, and many times the rates applied by farmers in some states. For example, the average application during 1953 was two pounds of fertilizer per acre of cultivated land in South Dakota, 14 pounds in Nebraska and only 51 pounds in Iowa.

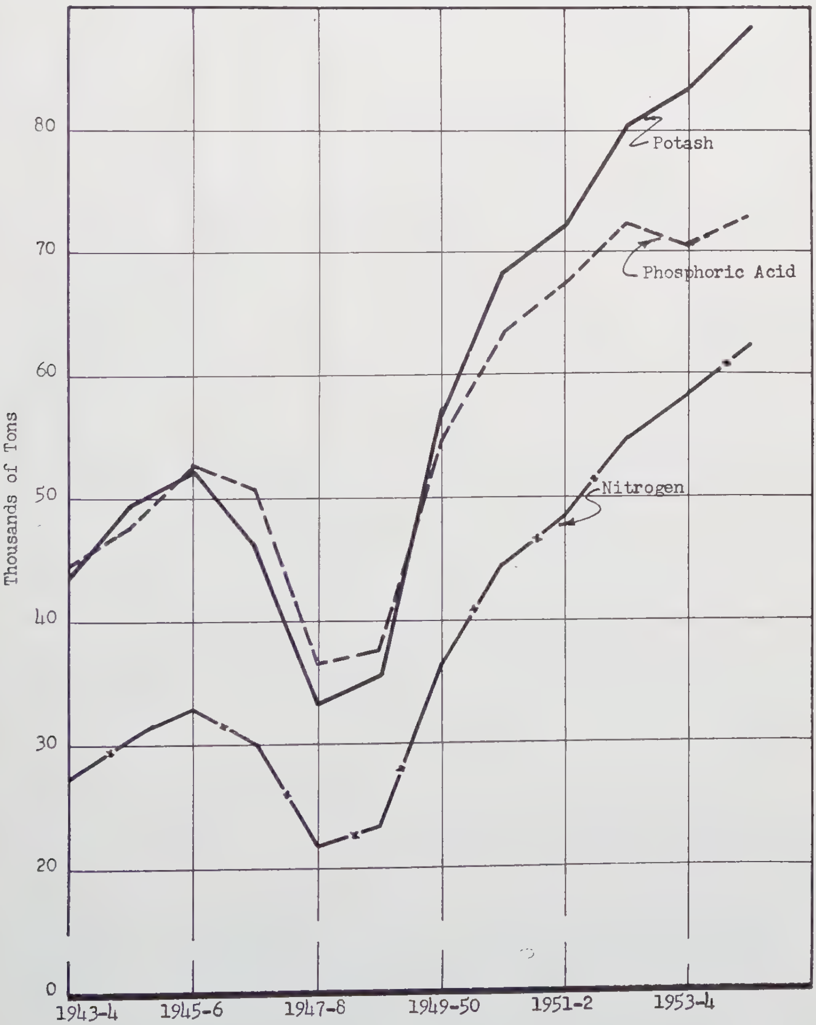

Figure 2. Consumption of N, P_2O_5 and K_2O in mixed fertilizers in Florida.

[1] National Fertilizer Review, XXIX No. 2: 16-18. 1954.

Total Consumption of Fertilizers.—Although Florida's 1,800,000 acres of cropland is a relatively small area compared, for example, to the 22,000,000 acres in Iowa; nevertheless her large acreage of heavily fertilized vegetable and citrus crops results in a high annual total fertilizer consumption as well as a high average per acre application. Total use of fertilizer in the state, excluding lime and other soil amendments, is reported[2] at approximately 1¼ million tons per year. In fact, Florida ranks third after North Carolina and Georgia in total consumption. The annual sales of mixed fertilizers and fertilizer materials during the past thirty years are shown in Figure 1.

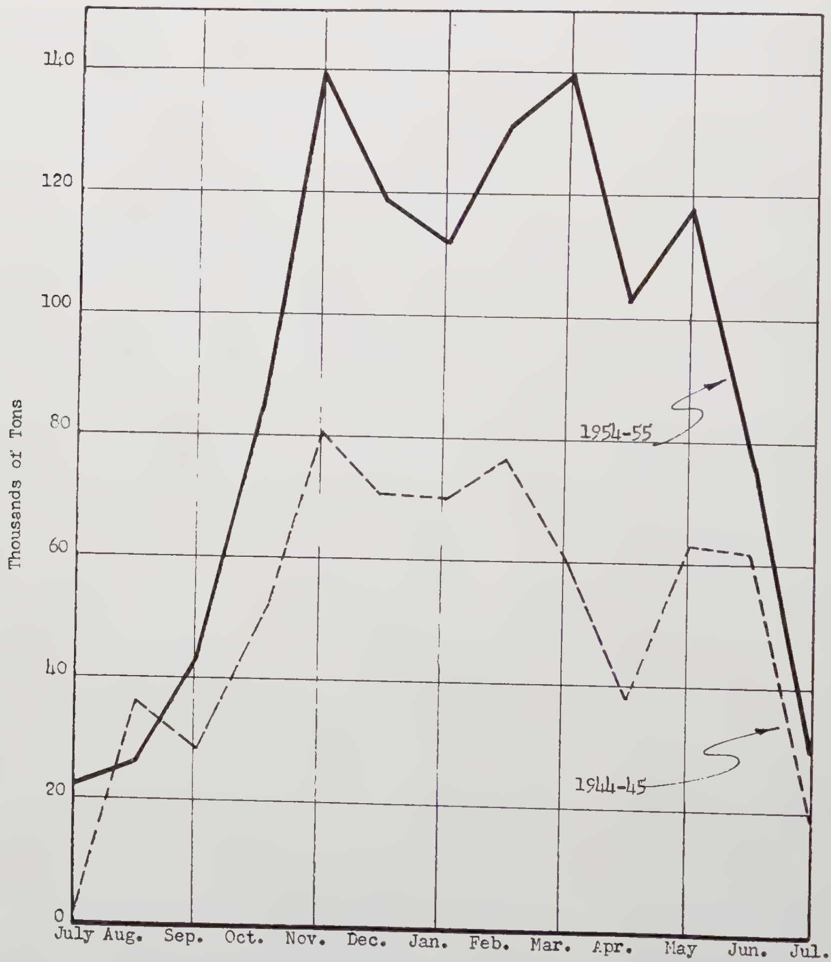

Figure 3. Monthly sales of mixed fertilizers in Florida (1954-55).

It can be presumed that the increase in research information on proper fertilization practices has had a marked influence on the general increase

[2] Plant Food Review. 1: 33-34. 1955.

in fertilizer consumption by the farmers. However, it can hardly be disputed that this upward trend is also related to general economic conditions. It is noted that the trend has been broken only during three short periods since 1925. These breaks in fertilizer sales are doubtless related to the low farm income during the depression of 1930-33 and the mild recessions in 1939-40 and 1947-48.

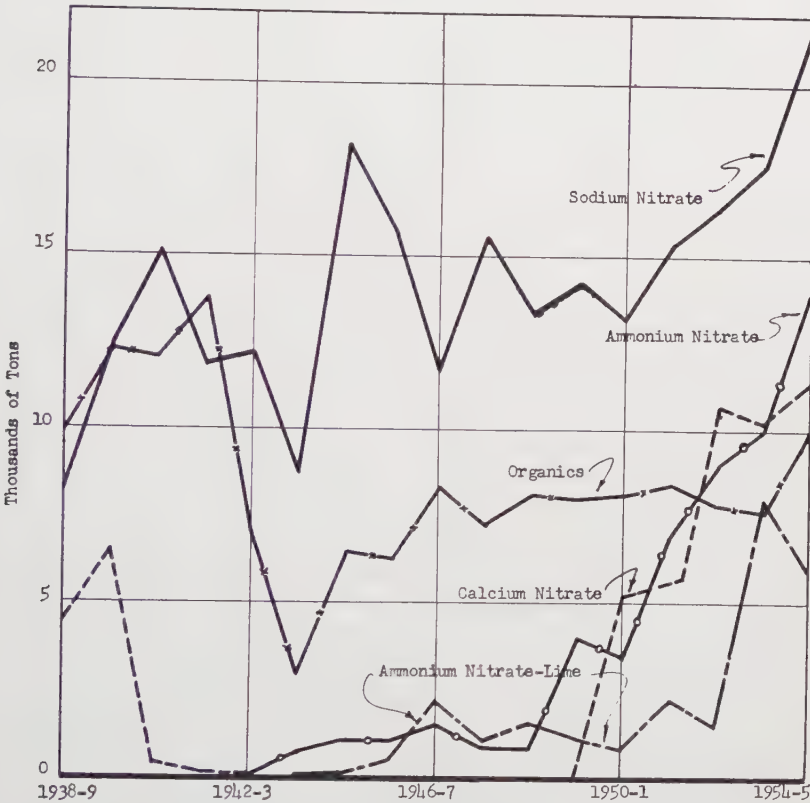

Figure 4. Sales of nitrogen materials in Florida (1938-1955).

Consumption of N, P_2O_5 and K_2O.—The consumption of nitrogen, phosphorus, and potassium closely parallels that of total fertilizer usage, as would be expected; however, significant trends in sales in recent years may be noted in Figure 2. While the popularity of higher analysis fertilizers has resulted in a more rapid increase in the consumption of N, P_2O_5 and K_2O than that for fertilizers as a whole, it is interesting to note that in recent years this increase has been due primarily to nitrogen and potash consumption.

The plant food content of fertilizers sold in the state has increased slowly. The average N-P_2O_5-K_2O content of mixed fertilizers has increased from about 17.1 to 22.2 percent during the past ten years. The trend toward higher analysis fertilizers has not been as rapid in Florida as in

most other areas. This is probably due to the continued popularity of low-analysis organic sources of nitrogen and to the proximity of phosphorus sources and the low content of sulfur in Florida soils which has encouraged the use of superphosphate in compounding mixtures.

The continual use of high rates of complete fertilizers on vegetable and fruit crops has resulted in an accumulation of phosphorus in the soil. As a result it has become a practice to reduce the amount or eliminate this plant food from the fertilizer program after several years. Since these crops account for a large percentage of the total consumption of fertilizers in the state (80 percent of the mixed fertilizers and 86 percent of fertilizer materials sold in Florida during the last fiscal year were sold in the central and southern sections) a leveling off in sales of phosphorus might be expected (Fig. 2).

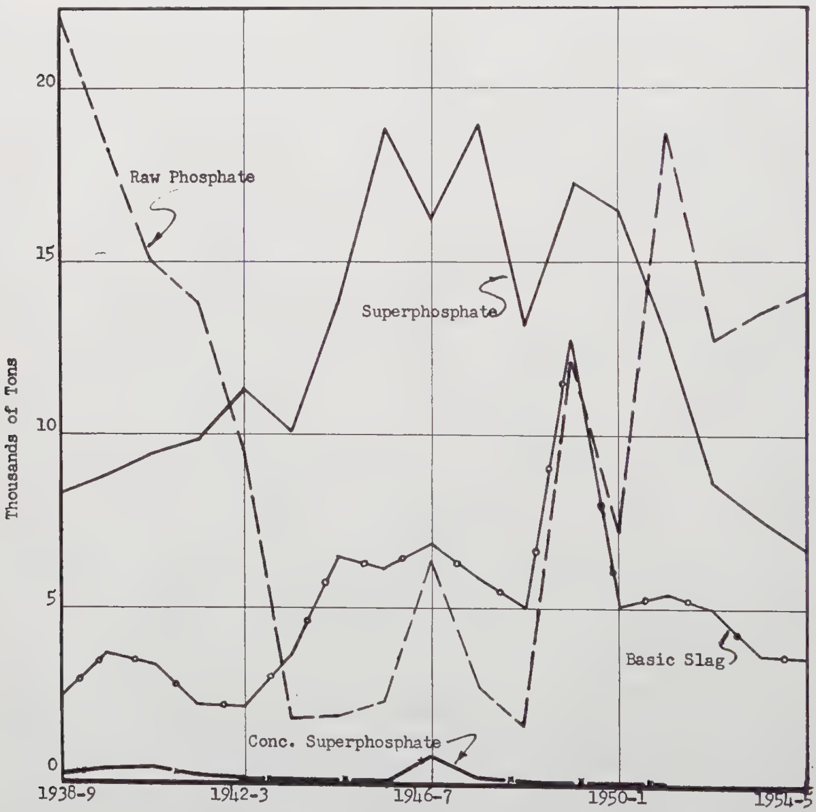

Figure 5. Sales of phosphorus materials in Florida (1938-54).

On the other hand, there is little tendency for the more mobile nutrients, nitrogen and potash, to accumulate in sandy soils. As a matter of fact these two plant foods are used in relatively large amounts by most growing plants and are seldom applied in excess.

Florida's mineral soils are uniformly low in nitrogen and potassium and the use of these fertilizer materials has closely followed the agricultural development in the state. There has been a particularly marked increase in the use of potassium and in the ratio of K_2O to N and P_2O_5 in mixed fertilizers.

Monthly Fertilizer Sales.—The sales of mixed fertilizers in the fiscal year 1954-55 are shown graphically in Fgure 3. The three peak periods, in the months of November, March, and May, correspond roughly to the three annual applications of fertilizers to citrus. Much of the fertilizer for field crops is sold during the February to May period, as can be seen from the graph which shows the data for 1944-45 as well as for the last fiscal year. The sales pattern has not changed materially in recent years. Some 77 percent of all mixed fertilizers are sold during the period November through May.

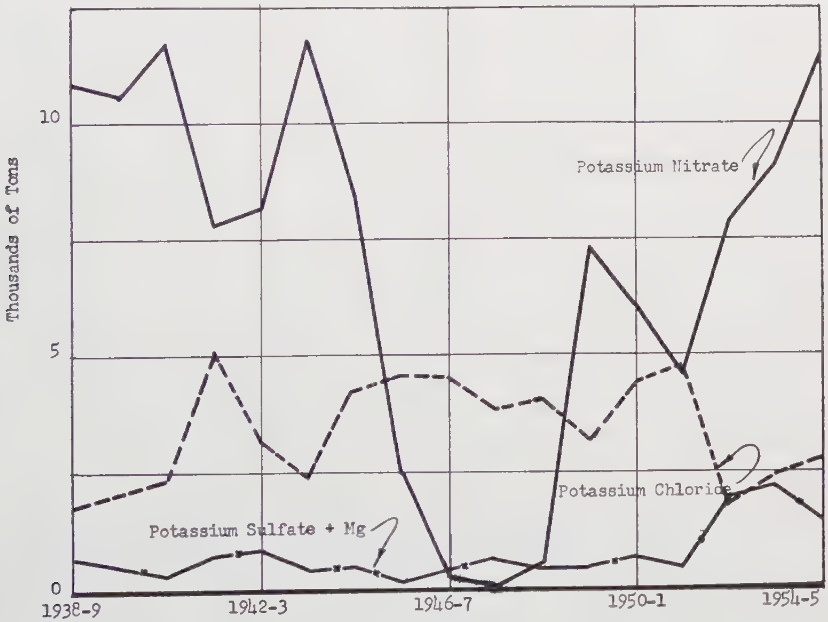

Figure 6. Sales of potassium materials in Florida (1938-1955).

Consumption of Fertilizer Materials.—In 1954-55 approximately 15,000 tons of nitrogen, or 25 percent of all the nitrogen used in Florida, was sold as materials for direct applications. Ten years ago the approximately 4,000 tons of nitrogen sold as materials represented only about 14 percent of the total. This rise probably reflects an increased interest in top-dressing with soluble nitrogen sources made available largely since World War II. Figure 4 shows the relative sales of nitrogenous materials since 1938-39. Sales of ammonium nitrate, calcium nitrate and ammonium nitrate-lime mixtures have risen rapidly during this period. Sodium nitrate has maintained its supremacy in total tonnage of materials; how-

ever, in terms of nitrogen, ammonium nitrate is in first position followed by sodium nitrate, calcium nitrate, potassium nitrate and urea.

The sales of phosphorus materials for direct application have generally decreased in recent years. The use of concentrated superphosphate in Florida, while never great, is no longer reported.[3] Sales of both superphosphate and basic slag have declined since 1950 and only the consumption of raw phosphates continues to show a general increase (Fig. 5).

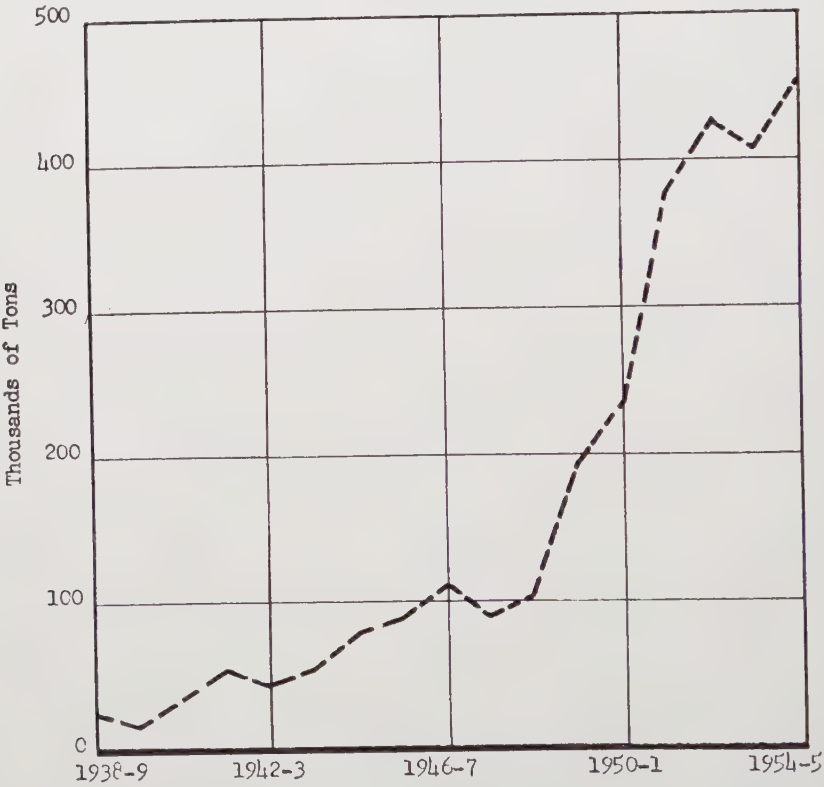

Figure 7. Consumption of agricultural limestone in Florida (1938-1955).

With the exception of sodium potassium nitrate, the sale of potash materials have shown no marked change since 1938-39. The sales of certain potash materials, as well as nitrogen materials, are closely related to their availability on the market. However, an interest in the use of potassium, as well as nitrogen, for top dressing certain crops probably has contributed to the substantial increase in sales of materials containing both of these plant foods in the last five years (Fig. 6).

Agricultural Limestones have experienced an 1800 percent increase in sales during the past 16 years, as shown in Figure 7. This increase

[3] State Dept. of Agriculture. Summary Report of Consumption of Fertilizer Materials in Florida. 1943-1955.

in consumption of high calcic and dolomitic limestones (not including hydrated lime and gypsum) from 25.000 tons to 450.900 tons has probably resulted from (a) an awareness of the importance of supplying additional calcium and magnesium as well as improving soil pH for good crop production on many of our soils, and (b) the expanded acreage of legume-grass pastures. However, on the basis of summaries of soil tests results, it has been estimated that an annual use of more than three times the present rate would be needed to maintain cultivated and pasture soils in the state at a desirable pH level for maximum production.

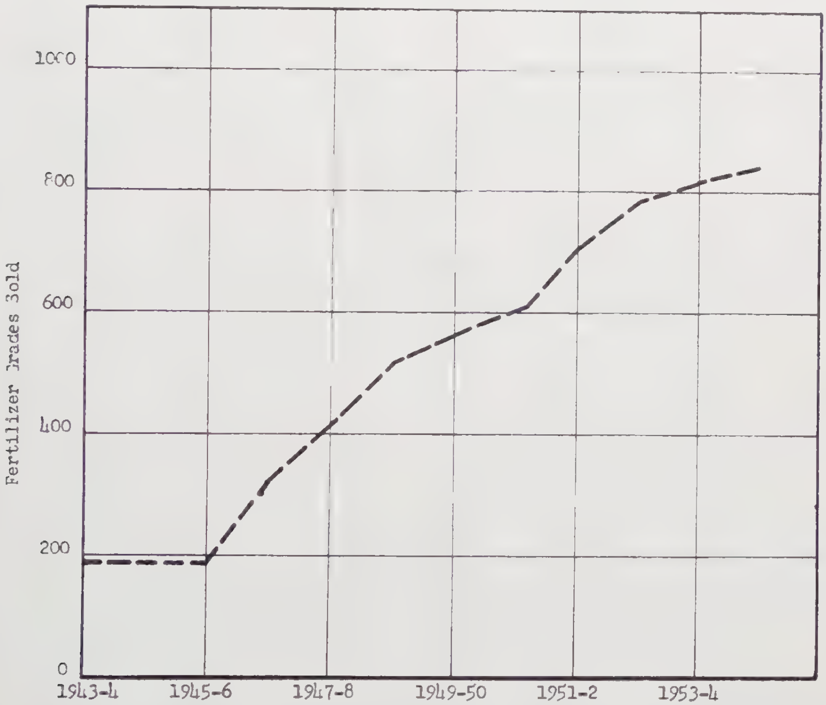

Figure 8. Number of fertilizer grades sold in Florida (1943-55) containing two or more major plant foods.

Grades and Ratios.—The total number of grades [4] of mixed fertilizers sold in Florida continues to increase. Since World War II the number has risen from 185 to 851 (Fig. 8). Actually, a total of 880 grades were sold in 1954-55; however, only grades containing two or more major plant foods were included in Figure 8. Since many growers demand special mixes, there are large numbers of grades sold in the state that are practically identical in plant food. For example, last year there were 26 grades sold in quantities exceeding 400 tons, all of which were classified as having a 1-1-1 ratio, Large numbers of grades were sold in each

[4] Grade, as defined in Florida Commercial Fertilizer Law, "means the minimum percentage of total nitrogen, available phosphoric acid, and water soluble potash stated in the order given—".

of the following ratios: 1-0-1, 1-1-2, 1-2-1, 1-2-2, and 2-1-2. This large number of grades takes on added significance when one considers that all Experiment Station fertilizer recommendations can be met with about 25 grades representing 15 ratios. It is estimated that, if necessary, this number of grades and ratios could be reduced to about 11 without undue inconvenience to any grower.

That many of the grades are special mixes and handled in small lots can be seen from the fact that one-quarter of the grades accounted for more than 96 percent of all fertilizers sold. About three-fourths of the fertilizer was mixed in only 34 grades and one-half of all sales were of the top eleven grades.

In spite of the fact that 4-7-5 has continued to be the most popular fertilizer grade sold in the state for many years, there is a trend away from 1-2-1 ratios toward 1-1-1 ratios. For example, the 6-6-6 grade jumped from tenth to second place in popularity since 1943-44 and the grades in the 1-1-1 ratio accounted for 20 percent of all sales last year. There also continues to be slow progress toward higher analysis fertilizers. The average N-P_2O_5-K_2O content of all fertilizers has risen from about 17.1 percent to 22.2 percent, as pointed out earlier. The percentage plant food content can be expected to increase slowly to about 26 to 30 percent; however, it will probably not materially exceed this level due to the need for sulfur which is usually absent in the more concentrated fertilizers.

PHOSPHORUS AND POTASSIUM REQUIREMENTS OF BLACKEYE PEAS GROWN ON EVERGLADES PEATY MUCK SOIL

CHARLES T. OZAKI*

During recent years, there have been increased acreages planted to blackeye peas (*Vigna sinensis*) on the organic soils of the Everglades region. Peas are generally planted on land which has previously been cropped to vegetables and which contains varying levels of residual phosphorus and potassium. The purpose of this study was to determine levels of phosphorus and potassium as determined by soil tests necessary for maximum yields.

PROCEDURE

The soil selected was an Everglades peaty muck which had been used in the past for permanent fertility studies at the Everglades Experiment Station, Belle Glade, Florida. The following treatments were applied: phosphorus—40, 80, and 120 pounds of P_2O_5 per acre derived from 20 per cent superphosphate; potassium—80, 160, and 240 pounds of K_2O per acre derived from muriate of potash. A check with no fertilizer added was included in both these treatment series. The treatments were arranged as a 4 x 4 factorial in a randomized block design with five replication.

All fertilizer materials were applied broadcast and disced into the soil before seeding. Soil samples were taken from these permanent-fertility plots before fertilization and again nearly one month after the treatments had been applied. The individual plots consisted of four rows, spaced three feet apart and 48 feet long. Early Wilt Resistant Ramshorn blackeye peas were seeded and later thinned to approximately six-inch spacing in the row.

RESULTS AND DISCUSSION

Analyses of soil samples taken before fertilization indicated the peaty muck soil had a pH of approximately 5.5 and a water-soluble phosphorus level of nearly 4 pounds per acre. The dilute acid-soluble (0.5 N acetic acid) potassium level varied from 50 to 70 pounds per acre, depending upon previous fertilizer treatments.

Samples taken a month after fertilization indicated that the following levels of soil phosphorus had been established: 3.5, 8.5, 11 and 19 pounds of P per acre. Analyses of samples for potassium indicated levels of 47, 118, 205, and 244 pounds of dilute acid soluble potassium per acre. The treatments and results of soil tests are presented in Table 1.

Weather conditions were favorable for the growth of peas and the young plants grew rapidly. As the plants began to set pods, early symptoms of potassium deficiency were noted on the foliage of plants on plots

* Assistant Chemist, Everglades Experiment Station, Belle Glade.
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receiving no additional potassium. The first indication of possible deficiency occurred as light straw-colored spots away from the margins of the younger, rapidly growing leaves. As the pods enlarged these spots coalesced and additional necrotic tissue developed along the leaf margins. Severe potassium deficiency symptoms accompanied widespread shedding of the leaves, a condition very evident at the first picking.

TABLE 1.—LEVELS OF PHOSPHORUS AND POTASSIUM IN THE SOIL ONE MONTH AFTER FERTILIZATION OF EVERGLADES PEATY MUCK SOIL.*

P_2O_5 Applied Lbs./Acre	P** Lbs./Acre	K_2O Applied Lbs./Acre	K† Lbs./Acre
0	3.5	0	47
40	8.5	80	118
80	11.0	160	205
120	19.4	240	244

* Each value average of 20 plots.
** Extracted with distilled water.
† Extracted with 0.5 N acetic acid.

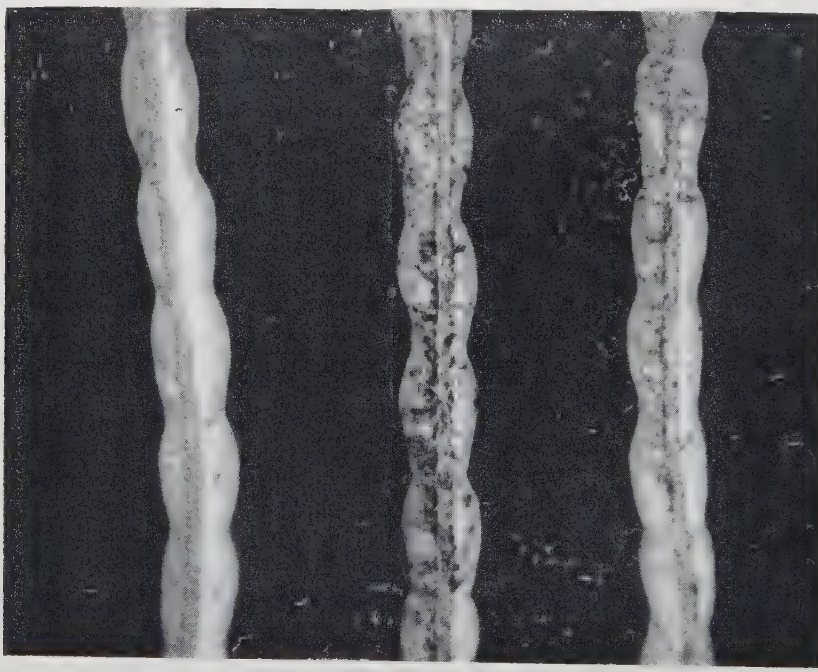

Figure 1. Typical symptoms of potassium deficiency on the pods of black-eye peas. Normal on right, deficient on left and center.

Potassium deficiency symptoms also occurred on the pods of these plants. Affected pods were characterized by reddish-brown necrotic spots which appeared on the outer surface. On many pods the region of the pod suture appeared to be most severely affected. The necrotic tissue was easily invaded by disease organisms resulting in rapid deterioration of the pods after harvesting. Typical symptoms of potassium deficiency on the pods of black-eye peas are shown in Figure 1.

TABLE 2.—Total Yield of Black-eye Peas as Influenced by Varying Levels of Phosphorus and Potassium in Everglades Peaty Muck Soil.

Level of K	Level of P				Mean Yields Lbs. per Plot*
	3.5	8.5	11.0	19.4	
47	383	394	350	390	76
118	511	507	494	528	102
205	511	502	516	510	102
244	516	500	511	507	101
Mean yield Lbs. per Plot	96	95	93	97	

* L.S.D. between mean yields of K .05 = 10.2
.01 = 13.7

The peas were harvested on two dates. Total yields obtained are given in Table 2. Significant increases in yield were obtained whenever the level of potassium as indicated by soil tests was increased from 47 to 118 pounds. No further increases were obtained at the higher levels of potassium. Additions of phosphorus gave no increases in yield.

TABLE 3.—The Phosphorus and Potassium Content of Petioles of Black-eye Peas as Affected by Varying Levels of Soil Phosphorus and Potassium on Everglades Peaty Muck Soil.

Level of P in Soil (Lbs./Acre)	Percent P* in Petioles	Level of K in Soil (Lbs./Acre)	Percent K* in Petioles
3.5	0.15	47	0.72
8.5	0.18	118	1.67
11.0	0.21	205	2.51
19.4	0.22	244	3.04

L.S.D. between means
for percent P .05 = 0 02
.01 = 0.03

P* quadratic

L.S.D. between means
for percent K .05 = 0.51
.01 = 0.69

K* linear

Petiole samples were collected from each plot shortly after visible symptoms of potassium deficiency occurred. The results of analyses are presented in Table 3. The potassium content of the samples ranged from 0.72 per cent where no potassium had been added to 3.04 per cent in samples from plots receiving 240 pounds of K_2O. The increase in potassium content of the petioles with increasing rates of K_2O was linear over the ranges studied. The phosphorus content of the samples was low; plants receiving no additional phosphorus contained 0.15 per cent phosphorus as compared to 0.22 per cent in samples from plots receiving the 120 pounds of P_2O_5. The quadratic component of the regression line for percentage of phosphorus with increasing rates of phosphorus was significant indicating a falling-off in relative uptake of this element at the higher levels included in the study.

SUMMARY

An experiment was conducted with black-eye peas on Everglades peaty muck to establish levels of phosphorus and potassium, as indicated by soil tests, which would be necessary for maximum yields.

Four levels each of phosphorus and potassium were applied in this study.

No increases in yield were obtained beyond the 118 pounds of K per acre. Severe symptoms of potassium deficiency were observed on the pods and foliage of plants growing in soil which had a level of 47 pounds of K. Although the lowest level of water soluble P was only 3.5 pounds per acre, no responses were obtained to further applications of phosphorus.

HERBICIDAL CONTROL OF WEEDS IN SUGAR CANE GROWING IN MUCK SOIL*

V. L. Guzman**

Three experiments will be reported here. The general procedure of these experiments with large size plots was similar to that outlined in previous papers (1, 2), if not otherwise stated. The herbicides used in these experiments are expressed in pounds per acre and were: 2,4-dichlorophenoxyacetic acid (2,4-D), sodium tricloroacetate (TCA), and 3-(p-chlorophenyl)-1-1-dimethylurea (Karmex W).

A—Control of Alexander grass (*Brachiaria plantigenea* (Link) Hitch C.) in stubble cane (second year)

The objective of this experiment was to find an effective herbicide or herbicides for the control of grasses. Alexander grass in particular, and to throw some light on the possibility of an effect on yields of sugar cane by weeding chemically without any cultivation for various periods of years.

In the first year (1953) of this perennial experiment it was found that a combination of TCA with 2,4-D amine salt or with Karmex W (formerly called CMU) gave better control of weeds (especially grasses) than 2,4-D sodium or amine salts alone. Yields were increased with TCA whether in combination with 2,4-D or with Karmex W over the cultivated check. It appeared that control of grasses and other weeds by chemical means alone is effective, and better than mechanical cultivation under the unusually weedy conditions of this experimental field.

RESULTS AND DISCUSSION

Table 1 lists the treatments applied during 1954. The original plan was to use 2,4-D sodium salt with TCA in treatment 3 and 2,4-D amine salt with TCA in treatment 4, but the possibility of drift damage to a neighboring field of peas prevented the use of 2,4-D. A day after the first application of the herbicides a 1.79 inch rain fell. Most of the chemicals under this condition gave fair to good control of weeds, especially the TCA and the Karmex W at the 5-pound rate. However, 4 weeks later new seedlings of Alexander grass began to grow rapidly. The second application of the herbicides did not kill the grass as well as the first. It was necessary therefore to apply an additional 20 pounds of TCA per acre on all plots except the check to control the grass. Two days before the TCA application, 2.04 inches of rain fell, and rainy weather continued for the most part of April. TCA gave good control of Alexander grass for 2 months. At the end of June a crop of Alexander grass appeared, especially in treatments 1 and 2, which had received

* This work was made possible by a Grant-in-Aid from United States Sugar Corporation.

** Assistant Horticulturist, Everglades Expt. Station, Belle Glade.

2 and 3 pounds of Karmex W respectively. By layby time large but scattered Alexander grass plants were present in most plots.

TABLE 1.—Herbicides Applied on Stubble Cane and Their Effect on Weeds, Yield of Cane, and 96° Sugar. South Shore Plantation, 1954.

Herbicides	Pounds/A. per Application		Control of Weeds*	Yields in Tons per A.	
	2/25 and 3/24	4/26		Cane	96° Sugar
1. Karmex W**	2	TCA 20	50	42.76	4.849
2. Karmex	3	TCA 20	55	42.39	4.819
3. TCA**	20	TCA 20	80	42.58	4.838
4. TCA	20	TCA 20† (Cultivated)	80	40.52	4.645
5. Karmex W**	5	TCA 20	70	44.76	5.121
6. Check		Cultivated and hoed	80	39.89	4.475
LSD .05				3.07	0.112

* No control—zero, excellent control—100.
** Commercial grade.
† Cultivated accidentally.

The average weed control with herbicides (Table 1) was fair, and better than the previous year. It seems that the heavy population of grasses and number of seeds in the surface of the soil had diminished to a point where commercial control was feasible. This was true also with mechanical cultivation in the check plots. The previous year 23 mechanical cultivations had been necessary to keep the check plots clean; this year 3 cultivations and one hand hoeing were sufficient to keep the check plots relatively clean.

Yields of cane were not significantly different from those of the check except for treatment 5 (5 pounds of Karmex W + TCA). It is suggested however that in such a large experimental field (over 30 acres), the variation within treatments is too large, making mathematical significance difficult. As such, if yields be taken as they are, all the herbicidal treatments produced better yields than the cultivated check plots (Table 1). The tremendous significance of this experiment is the relationship between cane and sugar yields for the chemically treated plots and the cultivated check. Better sugar yields were obtained with the herbicide treatments than with mechanical cultivation. This is a strong indication that control of weeds by chemical means, although in most cases it produces temporary burning of the cane leaves, is less detrimental to the crop. It is possible that mechanical roto-tilling breaks the cane roots, which in turn delays physiological maturity of the cane plant. Yields of cane may not be reduced, but maturity, judged from the viewpoint of sucrose storage, may be impaired.

The second significant point of this experiment is that commercial control of grass weeds and other weeds can be successfully accomplished by the use of herbicides with no mechanical or hand cultivation (Fig. 1). If the soil is not disturbed, and no new weed seeds are exposed to good conditions for germination, there is a strong possibility of reducing year after year the population of weeds susceptible to the herbicide used.

This appears to be the case in this particular experiment. The first year the control of weeds was an endless struggle due to the large number of weeds and weed seeds in the upper layer of soil. During the second year, weeds were more readily controlled than in the first.

The most promising accomplishment was that the returns from the chemically treated plots gave in all cases a monetary gain over the cultivated check plots (Table 2). Yield of 96° sugar was sufficiently increased to pay the cost of the herbicides and give a sizable profit.

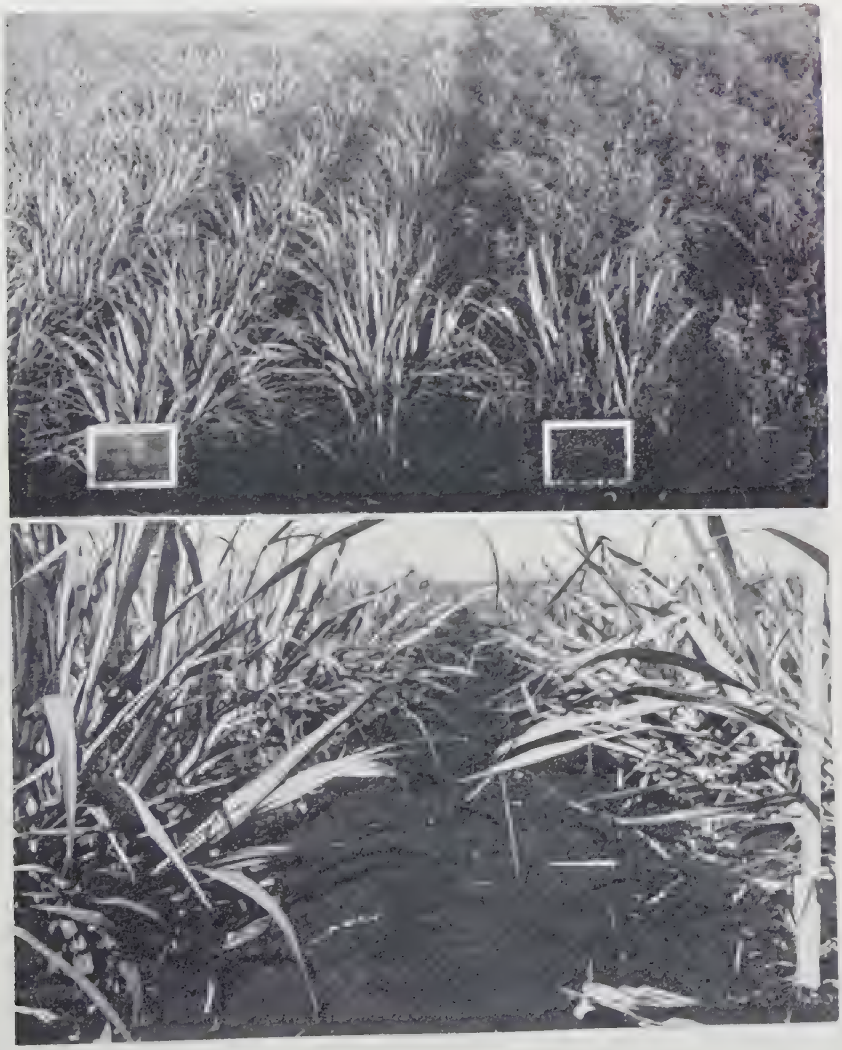

Figure 1. Upper picture shows chemical (TCA) weed control on the left versus mechanical control on the right. Note also the excellent control of weeds obtained with herbicides in lower picture.

TABLE 2.—Cost of Chemical Weed Control and Gain Over the Cultivated Check Plots in Relation to Yields of 96° Sugar Actually Obtained. South Shore Plantation, 1954.

Treatments*	96° Sugar Lbs./A.	Value** $/A.	Cost of Weed Control $/A.	Value Less Cost of Weed Control	Gain Over Check $/A.
1. Karmex W	9,699	$583.43	$19.90	$563.53	$42.33
2. Karmex W	9,638	579.76	25.90	553 86	32.66
3. TCA	9,676	582.05	23.70	558.35	37.15
4. TCA	9.291	558 89	23.70	535.19	13 99
5. Karmex W	10,242	616.10	37.90	578.20	57.00
6. Cultivated check	8,951	538.44	17.24	521.20	

* For rates of herbicides see corresponding treatments recorded in Table 1.
** At $6.0154 cwt.

B—Early vs. late control of weeds in stubble cane

In this study the effect of early and late herbicidal weeding was compared. In many instances, especially during the winter months after harvest, weeds are allowed to grow to a large size in the sugar cane fields before cultivation or herbicidal application is begun. This practice results in inadequate kill of large mature weeds and possible reduction of sugar cane yields. There are two main assumptions behind this procedure: first, that frost may kill the weeds at no cost, and second, that many of the winter growing weeds do not harm the cane plant growing in the rich organic soil where enough water and nitrogen are available, since the cane is growing slowly at this time of the year.

RESULTS AND DISCUSSION

Table 3 presents the treatments and the results obtained. Observations indicated that better weed control was obtained with the early use of 2 pounds of Karmex W plus 2 pounds of 2,4-D than with the late application of the same chemicals. Treatment No. 1 was practically free of weeds until lay-by time.

TABLE 3.—Effect of Early and Late Application of Herbicides on Weed Control and Yield of Cane and Sugar per Acre.

Treatments	Herbicides Applied Days from Previous Harvest	Weed Control %	Yields	
			TCA*	TSA**
1. Early (2,4-D + Karmex W)	25	95	46.25	4.554
2. Late (2,4-D + Karmex W)	120	30	44.22	4.386
L.S.D. (.05)			N.S.	N.S.

* Tons cane per acre.
** Tons 96° sugar per acre.

Yields of cane and sugar were not significantly different between the treatments (Table 3). However, in this large size experiment (each plot was 1.7 of an acre and replicated five times) the trend found should be of interest to the farmer. Yields of cane and sugar appeared to be better in the early treated plots than in the late ones.

C—Rates of 2,4-D and water for the control of broad leaf weeds in plant cane

This study was conducted in order to find the most effective rate of 2,4-D amine salt and water for control of weeds in sugar cane. Three rates, 1.0, 1.5, and 2.0 pounds of dimethylamine salt of 2,4-D were applied using ground equipment in all possible combinations with 10, 20, 30, 40 and 60 gallons of water as post-emergence to the cane and weeds, in a split plot design with sub-plots 1/50 of an acre.

TABLE 4.—Effect of Rates of 2,4-D Amine Applied in Various Amounts of Water on Weed Numbers and Yields of Sugar Cane.

	Treatments		Weeds Total	Yields	
	2,4-D Lbs./Acre	Water Gals./Acre		TCA*	TSA**
1	1.0	10	20	55.18	7.2
2	1.0	20	20	50.81	6.5
3	1.0	30	16	52.80	6.9
4	1.0	40	21	56.28	7.4
5	1.0	60	22	52.75	7.0
Totals			99	267.82	35.0
6	1.5	10	15	52.21	6.8
7	1.5	20	18	51.55	6.9
8	1.5	30	17	54.14	7.2
9	1.5	40	17	51.46	6.8
10	1.5	60	16	52.51	6.9
Totals			83	261.87	34.6
11	2.0	10	11	52.77	7.0
12	2.0	20	13	53.95	6.9
13	2.0	30	19	50.66	6.6
14	2.0	40	14	53.51	6.8
15	2.0	60	13	53.31	6.8
Totals			70	264.20	34.1
LSD	.05		N.S.	N.S.	N.S.

* Tons of cane per acre.

** Tons of 96° sugar per acre.

RESULTS AND DISCUSSION

Neither 2,4-D rates nor amounts of water used appeared to affect growth of the sugar cane plant, yields of cane or 96° sugar (Table 4).

The three rates of 2,4-D gave good control of weeds, and the differences in control of 1, 1.5 and 2 pounds of 2,4-D were not significant (Table 4). The number of weeds tended to decrease at higher rates of 2,4-D. The lack of significance is probably due to the variability of weed population in the plots and the random location in the plot where the count was made. If efficiency of the herbicides is rated by eye in comparison with the weeds growing in the untreated alleys it is found that the control of weeds with one pound is significantly inferior to that obtained at the 1.5 and 2.0 pound rates (Table 5). These results check very closely with observations made in the field. Control of weeds with 1.5 and 2.0 pound rates of 2,4-D was about the same.

TABLE 5.—EVALUATION OF WEED CONTROL BY THE RANKING METHOD.*

Replications	Rates of 2,4-D in Lbs./Acre			LSD	
	1	1.5	2.0	.05	.01
I	6.5	7.5	8.0		
II	6.5	8 5	9.0		
III	6.5	9.0	9 0		
IV	7.0	8.0	9.0		
V	7.0	8.0	8.0		
Total	33.5	41.0	43.0	3.23	4.70

* Zero, no control; 10, good to excellent control.

Field observations on the effect of amounts of water on the control of weeds were not easily noticeable. It appeared that slightly better control was obtained with 20-30 gallons of water per acre than with 10, 40, or 60, under the light weed growth which prevailed in the experimental field.

These results indicated that 1.5 pounds of 2,4-D amine salt in 20 to 30 gallons of water is sufficient for the control of weeds with no apparent damage to the cane plant.

SUMMARY

Experiment A is the second year of a perennial experiment in which herbicides were used for weed control as compared with mechanical means of disposing of weeds. There were five herbicidal treatments and one cultivated and hoed check.

Control of grass weeds was better with 20 pounds of TCA and the combination of 5 pounds of Karmex W plus 20 pounds of TCA than with 2 and 3 pounds of Karmex W each in combination with 20 of TCA. Commercial control of weeds was accomplished with all of the treatments. Plots chemically treated yielded more cane, more sugar and produced more money than the cultivated check plots, giving enough returns to pay for the herbicides and produce a profit.

Experiment B was established to determine the effect of early weed control vs late weed control with herbicides. Control of weeds was excellent with the early use of herbicides whereas the late application was quite ineffective. Yields of cane and 96° sugar seem to be in relation to the earliness and consequently effectiveness of weed control.

In Experiment C rates of 1.0, 1.5, and 2.0 pounds of 2,4-D amine salt were applied on sugar cane in all possible combinations with 10, 20, 30, 40 and 60 gallons of water per acre.

The results indicated that 1.5 pounds of 2.4-D is as effective as 2.0 pounds per acre. Although no clear cut rate was established in relation to amounts of water used. 20 to 30 gallons per acre seem to be adequate.

ACKNOWLEDGMENTS

Acknowledgment is due Messrs. J. W. Doty, B. W. Hundertmark, and I. M. Jackson of the United States Sugar Corporation for their valuable help in conducting these experiments.

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PROGRESS REPORT ON THE PROCESSING OF RAMIE FIBER FOR INDUSTRIAL USE

H. G. MORTON* and R. V. ALLISON*

INTRODUCTION

Any brief resume of the progress that recently has been made in the processing of ramie might well take for granted the many agronomic details that are involved in the growing of the crop under Florida conditions since the facts of abundant growth and production under Everglades conditions are well established and have been discussed a number of times in the past on occasions of this nature. Nevertheless, Figure 1 that follows is included to give an idea of the appearance of the crop at fairly average height when ready for harvest. In this same figure the inset shows a small, carefully measured area from which a fully quantitative harvest was made which yielded 1200 pounds per acre of shive-free ribbons after oven drying, from a single harvest. This, of course, represents *all* of the fiber available at the time of harvest and not what might be recovered by any particular method of field harvesting on a commercial basis.

That the above yield value is not excessive is well indicated by the fact that similar harvests of the same variety of ramie on a better type of soil that had been farmed to vegetable crops for a number of years and consequently had developed an unusually high fertility level as the result of accumulated fertilizer residues have shown yields as high as 1800 and even 2000 pounds of dry ribbons per acre from a single cutting. Certainly these values would seem to make the total yield of 1000 pounds per acre from all three cuttings that is commonly used in discussing the possibilities of ramie in Florida a fairly conservative one. The principal value of such total yields as referred to above is, of course, as an actual potential against which any and all methods of harvesting and ribboning can be appraised and improved at least to such extent as is economically justified by each.

Inasmuch as the characteristics of a field harvester-ribboner for bast fiber crops that is now quite well advanced in its development was discussed in some detail in a paper presented before this Society last November(1) we will not review this phase of the work further than to state that substantial progress has been made in this field of effort since that time and to show this harvester working on ramie in Figure 2 on the grounds of the Everglades Experiment Station. As a matter of fact it is expected that by next spring one or two other machines of promise will be available for testing.

Immediately following the paper referred to above on the program of last year the present speaker gave a brief discussion of the future of soft fibers in Florida(2). Mention is made of these papers since it is the intention in the present report to start as nearly as possible where

* Fiber Technologist, Florida Internal Improvement Board and University of Florida, respectively, Everglades Experiment Station, Belle Glade.

Figure 1. Ramie at full maturity ready for harvest. Upper left, an experimental area that has been harvested for total yield of fiber also revealing at the right in this small photo a limited view of a section of the field that has been harvested with the mobile harvester-ribboner shown in Figure 2.

we left off and discuss progress that has been made since that time. This, with respect to actual fiber preparation, will fall under two particular heads:

1. Improved accuracy in the stapling procedure especially where the fiber is to be worked on the cotton system, and

2. Very definite improvement in the opening of the fiber following degumming in preparation for the drawing and spinning operations that are to follow.

By way of preparing the fairly crude though well-aligned ribbons such as are produced by the Cary harvester-ribboner for the use of the domestic market, which is the only market of real interest to Florida growers, the first need is for the complete removal of woody particles

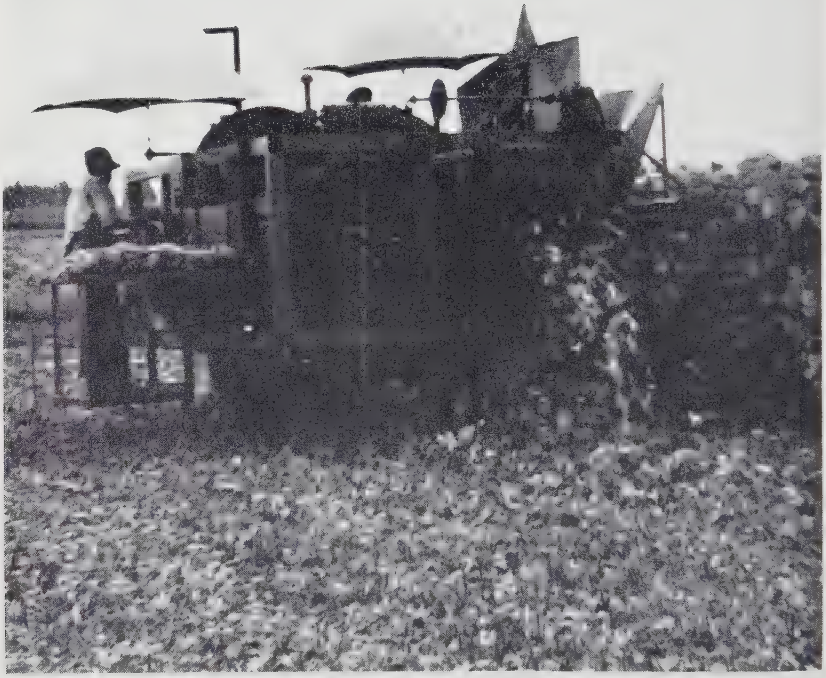

Figure 2. Cary harvester-ribboner at work on the grounds of the Everglades Experiment Station, July 1955. Note trash streaming from the machine at the right with accumulation of ribbons on the platform at the left where they are placed by the attendant after twisting them into small, easily handled "Stricks". After an accumulation of 400-500 pounds the bundle is tied tightly with two strong ropes already in position and rolled off onto the ground for later loading on a truck carrying a small crane for the purpose. The ribbons are then taken to the drying plant.

(shive) along with as much bark as possible and arranging the fiber strands in the fullest possible alignment for stapling. Accuracy in this latter phase of preparation is, of course, particularly important where the fiber is to be worked on the short reaches of cotton equipment, as already has been mentioned. Fortunately there are several machines in process of development for the cleaning operation which should be ready for testing and comparison to existing equipment by the time of the first spring harvest.

STAPLING

Improvement in the stapling operation is largely a matter of more careful attention to strictly mechanical operations which involve the cleaning and preparation of the ribbons on the one hand and their actual handling or manipulation, on the other, during the stapling operation by which they are cut into predetermined lengths varying from 1 inch or more up to 3 inches for the cotton system. Longer staple is prepared for the worsted or woolen systems as well as the linen or spun-silk sys-

tems. Much improvement has been made at this stage of the handling during the past two or three months.

CARDING

A most striking improvement also has been made in furthering the adaptability of ramie staple to conventional cotton equipment through the recent development and patenting (August 2, 1955) by Mr. W. L. Davis of Danville, Va., of a Modified Roll Stand whereby the capacity or reach of conventional cotton spinning equipment can be extended from less than two inch staple to more than three inches at a comparatively limited expense and without in any way impairing the original equipment which readily can be returned to the standard form of operation by removal of the superimposed parts. This improvement is described in full detail in patent No. 2,714,228. The implications in connection with the potentials of this equipment insofar as relaxing finesse as to accuracy of stapling for the cotton system is concerned, are readily apparent.

In support of the adaptability of fiber up to 3 inch staple by the above application to the cotton system satisfactory opening and carding was first accomplished by the use of a conventional cotton card to which has been attached a licker-in roll designed especially for synthetic fibers and built by Ashworth Brothers, Inc., of Charlotte, N. C. Simultaneously the top flats on the card were opened to about 30 thousands of an inch instead of 12 that is commonly used for cotton. Extension of this opening avoided much obvious damage to the fiber and most of the considerable amount of fly that was produced by the closer setting. This procedure will only handle ramie stapled up to three inches.

Subsequently even better results were obtained thru the use of a card designed all the way thru for use on synthetic fibers since it will handle the longer fibers up to 6 or 8 inches as well as the shorter staples for the cotton system. The first card of this type that has been tried in this work was built by Proctor and Schwartz of Philadelphia whose staff have very kindly run a number of experimental samples sent them for this purpose.

It cannot be too strongly emphasized that the success of these operations and the subsequent acceptability of the fiber to industry depends on an accurate job of stapling at such predetermined length as has been decided upon especially for the cotton system, as well as carefully considered treatment of the fiber for softening and a good preliminary opening as by a single or double passage thru an SRRL unit before carding is undertaken.

Fortunately, all of the large textile mills with whom friendly and effective working relationships have been established have excellent research divisions. Thus, as a result of the work that is under way with several of these groups a great deal of new and necessary information on the processing of ramie fiber is now becoming available and is proving of very great assistance in developing and extending the interest of industrial workers in this really extraordinary fiber.

GENERAL CHARACTERISTICS OF THE FIBER

In order to describe ramie fiber in comparison to cotton, wool and such man-made synthetics as rayon, nylon, dacron, orlon, etc., in terms

of relative weight and size the term DENIER is used. This is actually the calculated weight, in grams, of a single fiber 9,000 meters long. Thus, if 9,000 meters of a ramie fiber of a particular size is found to weigh 4.5 grams then it is said to have a denier of 4.5. The average denier of the commercial ramie grown in Florida may be regarded as ranging from 5.5 to 7.0 denier. In general the coarser fibers are at the base of the stem and the finer ones at the top with those of medium size occupying mid-stem positions, at least according to present methods of measurement. While cotton and wool fibers are normally much finer than the average for ramie referred to above there are a number of fine-fibered ramie varieties that have an average denier of 3.0 to 3.5 with still finer sizes, of course, in the top. Furthermore, considerable work is in progress at the Everglades Experiment Station in an effort to find varieties with fine fiber which, at the same time are good yielders, which is not necessarily the case in such presently available varieties as Tatsutayama and Kagasei.

The denier of synthetic fibers, as with their staple, is entirely a matter of mechanical manipulation. It is in the natural staple length, of course, that ramie has a tremendous advantage over all other natural fibers, the range being from two inches or less up to twenty inches or more, whereas cotton is conventionally classified as "Extra Long" from 1⅜″ to 1⅞″, "Long" from 15/16″ to 1⅜″ and "Short" from 8/16″ to 15/16″. On the other hand such short fibers as those of flax must be allowed to retain enough of their natural waxes to cement them into spinnable fibers, a fact that causes them to weather quite poorly under many conditions of exposure.

The relative strength of the various natural fibers is a matter of frequent reference when their merits are being compared. Suffice it is to say that ramie, when properly degummed and softened, is so much stronger than any of them that it is doubtful if there are many practical uses to which it can be put that will require its full strength. That makes the consideration of this factor something like the 120 miles per hour that is indicated on the speedometer dial of your Packard or Cadillac; for while it is unlikely that you will ever drive that fast, still it is nice to know that you have that reserve—just in case. Furthermore, ramie develops greater additional strength upon wetting, up to sixty (60) percent, whereas synthetic fibers, with but few exceptions, lose strength under such condition, some of them to quite a substantial extent; as does also wool. None of the synthetics are known to gain strength upon wetting. Since fully degummed ramie is about 98.5 percent alpha-cellulose it is highly resistant to mildew, a fact that immediately raises many implications as to its preferential use especially under tropical and subtropical conditions where the combination of temperature and humidity is so tremendously destructive of ordinary fibers and fabrics of almost any kind.

SPINNING SYSTEMS IN THE UNITED STATES

The spinning systems in use in the United States fall naturally into three general classes insofar as range of staple length for each is concerned. These are:

1. The cotton system is for short fibers, formerly ½″ up to 1¾″ or 2″. However, with the mechanical improvement that recently has been invented and patented and which is readily adaptable to conventional

spinning equipment a reach of 3 inches or more seems readily possible. This, of course, will be a big advantage for use with ramie whether in pure staple or for blending with cotton. The cotton system is, of course, the most economical spinning system in the world by a considerable margin, at least insofar as the first cost is concerned. It is on this account that we are working with the Research Divisions in several large cotton mills. Very satisfactory progress has been made in producing a 100 percent ramie yarn in 9/1 as well as blends of ramie and cotton in even smaller counts, all of which promise to be competitive in cost.

2. The woolen-worsted system, which will take staple lengths of 3 to 6 inches is of considerable advantage to ramie since it gives the fiber greater strength through the added length that is usable in this method. The production cost is, of course, substantially greater than that of the cotton system.

3. The linen spun-silk system, with the longest reach of all, 7 to 10 or 12 inches, offers the ultimate to ramie in gaining strength through length of staple. However, in order to spin very fine numbers on this system very fine fibers must be had—of the order 2.75 to 3.5 denier. Likewise, the cost of yarn from this system may be 1½ to 2 times as much as from the cotton system. Therefore, determination must first be arrived at as to what the yarn is to be used for.

With well-processed ramie now becoming available for the domestic market in quantity and at any staple length that may be desired, many far-seeing cotton people are beginning to feel quite strongly that this fiber may prove a definite asset to cotton rather than a competitor because of the wide variety of essentially new fabrics that can be produced through the blending of the two fibers in predetermined proportions according to the characteristics that are desired in the end product.

FIBER CONSUMPTION IN THE UNITED STATES

The table below, which shows total fiber consumption in the United States for the years 1945 through 1954, is quite significant in indicating the constant level of consumption at which cotton has maintained through these years and the complete manner in which synthetic fibers apparently are absorbing the progressing fiber demands of the increasing population during this period. It is repeated here particularly to make some minor corrections in the form used in the previous discussion(2); also by way of extending it to include wool. There are also those among the cotton people who feel that had blending studies of cotton and ramie, which are now in process of development, been started ten years ago the outlook for improved cotton consumption in the future might be quite different from what it is at the present time.

PRESENT ACREAGE AND PRODUCTION

A brief survey of ramie production in Florida for the year 1954 would seem to be the most logical basis for an estimate of present production since the 1955 harvest is still in progress and the overall yields have not yet been calculated. (Newport Industries, Inc., is now harvesting into its 4th crop as of 11/29/55).

Total Fiber Consumtion in the U. S. for the Years 1945 to 1955.*
(Unit 500 Pound Bales)

Year	Cotton	Man-Made Fibers	Wool
1945	9,144,444	1,638,400	1,290,000
1946	9,832,814	1,859,400	1,454,000
1947	9,546,151	2,075,200	1,416,000
1948	9.095,142	2,444.000	1,408.000
1949	7,873,203	2,173,000	1,022,000
1950	9,649,675	2,986.200	1,294,000
1951	10,036.880	2,948.600	990.000
1952	9,180,101	2,939,600	954 000
1953	9,308,143	3,044,600	1,008.000
1954	8,533,464	2,993,200	782,000

* Textile Organon, March 1955.

The largest grower of ramie, Newport Industries, Inc., with 2500 acres produced 2 million pounds of dry ribbons in 1954. Of this amount about 200,000 pounds were degummed in the Company's plant at Clewiston and sold for domestic consumption. The balance was released for export to Japan, Switzerland, France and Germany in the undegummed form. Other growers, including Arlington Ranch, 240 acres; Alex Ramey 1000 acres; Shawano Development Corporation 1000 acres and the Yount-Kruse plantation, 200 acres; are ready to produce marketable fiber, as well as root-stock for acreage expansion in the Belle Glade area. As of the end of the year (1955), therefore, there should be a total of very nearly 5000 acres of ramie ready for active production in the spring of 1956. This, it might be noted, is about as much as or even more than is said to be grown in all Japan where there are several large processing mills for this fiber alone. Such a limited acreage in that country is the obvious result of competition with food crops under such highly populated conditions. Naturally this causes that country, as well as Germany, Switzerland, France and Italy, where it cannot be grown at all, to seek a major portion of its raw fiber requirements from other sources—such as Florida. However, it should be emphasized that this is an exceedingly small acreage for this country should substantial interest in the use of this fiber develop even on the part of one medium sized mill!

In this connection it might be noted that ramie production in the Philippines has increased from practically zero immediately following the war to 6500-7000 acres by July of 1955.

RAMIE USES

An almost unlimited number of uses could be listed for ramie beginning with the finest of sheer fabrics and concluding with such industrial and heavy-duty items as canvases, webbing, packing, halyards and draper materials. While we are preparing to go along with the rapidly developing interest in blending with cotton and hope to see a really constructive and effective program of research in this field developed over at the USDA Regional Laboratory at New Orleans, we really believe the most constructive and practical use for the fiber from every standpoint is in

the field of heavy-duty items since it is in this field that it will find its greatest opportunity for service from the standpoint of strength and durability.

Naturally no little emphasis in all of our work has been placed on ramie as an extremely DURABLE fiber; also on the fact that its production on a large scale in Florida is not only HEMISPHERIC and CONTINENTAL but, in fact, U. S. This emphasis, of course, has been and will continue to be for the ear of our good and ever-alert friends in the Department of Defense where so much grave concern has been expressed in the past over the availability of an adequate supply of just such a fiber without the trials, tribulations and actual dangers of water transportation from a distance especially during war time. It is our feeling that the potential place of this fiber in our National Defense picture cannot easily be over emphasized.

Even at the risk of repeating something that has been said a great many times, ramie, because of its great versatility based on length and strength of fiber, absorbency, ease of dying, etc., is the very finest of all natural fibers for blending with other fibers, either natural or synthetic. The outlook for blending with cotton already has been mentioned. In the instance of wool, its use in a proportion as low as 25 percent not only strengthens the yarn, or the fabric in which it is used, but stabilizes the product against stretch and shrink. As to its use with synthetic fibers such as nylon or dacron, it literally breathes life into such yarns or fabrics by giving them absorbent qualities which such completely solid and inert materials can never have when used alone. Many other blending relationships could be mentioned, all of which, of course are quite aside from the really great number of unique uses for the fiber in its pure form.

FOR THE IMMEDIATE FUTURE

1. It is planned that much effort will be given to the improvement of ramie ribbon quality and processing to and thru the stapling, degumming and softening stages as the best insurance for a uniformly superior product at the carding level.
2. Cooperation will be maintained with industrial research units beginning at the carding stage and carrying thru the spinning and weaving stages to comprehensive tests on yarns and fabrics.
3. The development of a comprehensive research program in blending of ramie and cotton at the Southern Regional Laboratory, New Orleans, will be encouraged in every possible way as will also a fully complementary program of testing at all stages of the work with the fiber at the U. S. Bureau of Standards, Washington, D. C.
4. Definitely seek the return of fiber crops (in this instance the stem or bast-fibered crops ramie and kenaf) to the list of those eligible for loans by Farmers' Home Adminitsration.

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SYMPOSIUM: NITROGEN FERTILIZATION

Wednesday, November 30, 8:30 A.M.

G. M. Volk,* Moderator

AN EVALUATION OF SOME NITROGEN SOURCES FOR GENERAL FARM CROPS GROWN ON RED BAY FINE SANDY LOAM

W. K. Robertson and C. E. Hutton**

There have been no published data on the relative effect of nitrogen sources on general farm crops in West Florida. Usually the choice of nitrogen sources, on crops where the fertilizer bill is a large part of the cost of production, is based on economy. No attention is paid to their effect on crop yield or chemical status of the soil. There has, however, been considerable work on other crops and in other areas, which may be applicable.

Studies in the greenhouse by Volk(5) showed a marked difference in the rate of availability to oats of nitrogen derived from duramene, urea, cottonseed meal and calcium nitrate. Volk(6) found later, in an outdoor lysimeter study, no measurable differences in leaching of nitrogen from soil supporting Bahia, Pangola and Bermuda grasses where urea, ammonium nitrate and sodium nitrate were used as nitrogen sources. However, he did find a marked difference in soil pH as a result of nitrogen sources. This latter finding could be an important factor in choosing a nitrogen source in West Florida. It has been found that phosphorus fixation in the Red Bay soil decreases with increasing pH levels due to the conversion of iron and aluminum phosphates to the more available calcium phosphates(4). Hence it is possible that nitrogen carriers that increase the pH might have a beneficial localized effect on the availability of soil phosphorus. Where the soil pH is purposely held low as in the case of potatoes to control scab the soil conditions are such that nitrification of ammonium and other reduced forms of nitrogen is too slow to supply the nitrate form of nitrogen in sufficient quantities and nutritional leaf roll results. For this reason it has been found necessary to supply at least part of the nitrogen in the nitrate form(7).

The object of this study was to determine the effect of certain nitrogen sources on some of the general farm crops of West Florida. Crop yields and their effect on the chemical status of the soil were the criteria of response. The soil on the experimental site was predominately Red Bay fine sandy loam.

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* Soil Chemist, Agricultural Experiment Station, Gainesville.

** Assistant Soils Chemist, Agricultural Experiment Station, Gainesville and Vice-Director in Charge, West Florida Experiment Station, respectively.

Florida Agricultural Experiment Station Journal Series, No. 450.

METHODS

The experiment was initiated in the fall of 1949. Treatments were made on a three-year rotation, consisting of oats for grain followed by soybeans the first year, oats turned down followed by peanuts the second year and lupines plowed down followed by corn the third year. The main treatments were laid out in a randomized block design replicated three times. The treatment plots were divided into three parts so that each year of the rotation appeared every year in all of the replicates. Lime was applied to half of each plot but was not randomized. The experiment was terminated in the fall of 1953 except for the corn phase which was continued in 1954. The areas of each plot devoted to the crops of the other two years of the rotation was used for two new nitrogen experiments on corn. One of these was to compare ammonium nitrate and uran 60, a solution containing 60% ammonium nitrate. The second was a nitrogen rate study. Treatment differences were not significant in these two experiments, possibly because dry weather in 1954 lowered the overall yield and narrowed responses. These data are not reported.

The nitrogen sources tested were $NaNO_3$, urea, Cyanamid, NH_4NO_3, $(NH_4)_2SO_4$, $Ca(NO_3)_2$ and Duramene.[1] The compounds contained 16, 42, 21, 32, 20, 15 and 17 per cent nitrogen respectively. These sources were tested every year on all crops with the exception of $Ca(NO_3)_2$ and Duramene. $Ca(NO_3)_2$ was used in 1951 only, but because of its hygroscopicity it was abandoned and replaced by Duramene for the remaining years of the study.

Nitrogen from the various sources was applied at the rate of 30 lbs. per acre on the non legumes and 15 lbs. per acre on the legumes. A uniform application of 100 pounds of P_2O_5 from superphosphate and 100 lbs. of K_2O from muriate of potash was added to each crop. This was thought to be sufficient to keep phosphorus and potash from limiting yield. It was later found that, due to the high fixation capacity of the soil for phosphorus(3), the phosphorus application might have been too low the first year. However, because of the greater availability of residual fertilizer phosphorus than virgin phosphorus(3), the phosphorus applied should have been high enough in succeeding years. One ton of dolomitic lime per acre was added to the limed plots in the fall of 1949 and 3300 lbs. of dolomitic lime per acre was added to the same plots in the spring of 1952.

The soil samples collected were composites of the 0″ - 6″ layer of the profile. Prefertilization samples were taken in 1949 and chemical data from these were used to determine the required rates of fertilizer. Samples were taken again in 1952. The pH data from these resulted in the application of the additional lime mentioned above. Final samples taken in 1954 at the end of the experiment were analyzed to determine the effect of the various treatments on pH, exchangeable calcium, potassium and magnesium(2), phosphorus, extracted by the Bray method(1), organic matter determined by the Walkley-Black method(8) and total nitrogen.

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[1] Urea formaldehyde compound on wood waste made available by Newport Industries, Pensacola.

TABLE 1.—CORN YIELDS IN BU./ACRE SHOWING ANNUAL RESPONSE TO NITROGEN SOURCES.

Treatment	1950	1951	1952	1953	1954	Average
$NaNO_3$	66.0	72.9	26.8	71.4	42.2	55.9
Urea	66.5	77.9	25.8	72.8	39 2	56.4
Cyanamid	59.6	72.6	27.8	68.8	41.7	54.1
NH_4NO_3	63.0	72.0	31.1	70.6	41.3	55.6
$(NH_4)_2SO_4$	62.0	77.0	27.3	71.4	35.5	54.6
Duramene	65.0*	63.0	28.1	68.4	40.0	52.9
Average	63.7	72.6	27.8	70.6	40.0	54.9
L. S. D. 5%	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

* In 1950 $Ca(NO_3)_2$ was substituted for Duramene.

TABLE 2.—ANNUAL CORN YIELD RESPONSE TO LIME IN BU./ACRE SHOWING EFFECT OF NITROGEN SOURCES.

Treatment	1950	1951	1952	1953**	1954*	Average
$NaNO_3$	—3.7	8.4	5.1	8.9	8.3	5.4
Urea	—5.2	4.2	3.3	10.6	9.0	4.3
Cyanamid	—0.5	3.5	5.1	2.5	3 3	2.6
NH_4NO_3	1.1	4.3	2.5	8.5	4.0	4.0
$(NH_4)_2SO_4$	—5.9	6.6	—1.7	4.3	0.4	1.3
Duramene	0.7	1.1	3.4	1.8	—	1.8
Average	—2.2	4.7	2.9	6.1	5.0	3.2

* Data significant at the 5% level of probability.
** Data significant at the 1% level of probability.

TABLE 3.—PEANUT YIELDS IN LBS./ACRE SHOWING ANNUAL RESPOSE TO NITROGEN SOURCES.

Treatment	1950	1951	1952	1953	Average
$NaNO_3$	2030	960	1400	1360	1440
Urea	2100	900	1570	1480	1520
Cyanamid	1910	1000	1540	1360	1460
NH_4NO_3	2020	910	1620	1420	1480
$(NH_4)_2SO_4$	2030	920	1470	1260	1420
Duramene	2050*	980	1560	1380	1500
Average	2020	940	1530	1380	1470
L. S. D. 5%	N.S.	N.S.	N.S.	N.S.	N.S.

* $Ca(NO_3)_2$ substituted for Duramene in 1950.

RESULTS

Table 1 contains a summary of the corn yield data showing the responses to sources of nitrogen for five years. There was no significant response to nitrogen sources. Cyanamid had the lowest yield in 1950, Duramene was lowest in 1951 and 1953, and urea and $(NH_4)_2SO_4$ were lowest in 1952 and 1954 respectively. These data indicate that there was no one source consistently poorer or better than the others. Statistical analysis of the data by years showed the average effect of nitrogen sources to be non-significant.

The seasonal variation (72.6 to 27.8) was attributed to poor rainfall distribution. Dry periods in 1952 and 1954 reduced yields regardless of treatment.

Corn yield response to lime for the various years is shown in Table 2. Negative values indicate the number of bushels that the unlimed plots were better than the limed, and positive values vice versa. Of these data, only those for 1953 and 1954 were significant. The negative response in 1950 may be due to a temporary reduction in availability of some plant nutrient.

Nitrate of soda, a nitrogen source known to be one of the most alkaline in reaction, in the soil(6) gave the best average lime response. This indicates either that nitrification is slow in these soils or that the lime applied was not sufficient to promote optimum nitrification. This supposition is supported in part, since an ammonium source, $(NH_4)_2SO_4$, with an acid soil reaction was poorest.

Lupine yields were taken in 1952 and 1953. Sources of nitrogen, lime and the lime-treatment interaction [2] were non-significant. Yields were low because of diseases. The average dry weight was only 450 lbs. per acre. The lupine, however, contained 3.5% nitrogen; this amounts to almost 16 lbs. of nitrogen per acre in the above-ground portion. If this is added to the nitrogen in the root portion, it is estimated to approximate 32 lbs. of nitrogen per acre. This accounts for the relatively high corn yields in 1950, 1951 and 1953 (Table 1) even though the nitrogen applied (30 lbs., per acre of N) was less than the recommended rate for these soils(3).

The peanut yields are shown for the various years in Table 3. Responses to treatments were not significantly different in any case. Over a ton per acre was produced in 1950 and it is suspected that the smaller yields in 1951, 1952, and 1953 were due to weather conditions. Peanuts grow later in the season than corn, and dry periods that affect corn have less effect on peanuts. The best corn yields were obtained in 1951 (Table 1), but in 1951 peanut yields were lowest (Table 3).

The effect of lime on the peanut yield response to nitrogen sources is shown in Table 4. Lime was significant only in 1953. This was probably due to the second application of lime in 1952 which by this time had had time to dissolve and become available. The effect of nitrogen sources on the lime response for the four years was very small.

Yields were taken of the oats to be plowed down as a green manure crop for two years. Sources of nitrogen, lime and the lime-treatment interaction were not significant. Since only 30 pounds of nitrogen per

[2] Treatment refers to sources of nitrogen when used in lime-treatment interaction.

TABLE 4.—ANNUAL PEANUT YIELD RESPONSE TO LIME IN LBS./ACRE SHOWING EFFECT OF NITROGEN SOURCES.

Treatment	1950	1951	1952	1953*	Average
$NaNO_3$	—60	130	20	200	60
Urea	—130	170	20	250	70
Cyanamid	10	—10	—20	240	50
NH_4NO_3	—70	—20	—10	130	10
$(NH_4)_2SO_4$	—200	—120	40	230	—10
Duramene	40	90	—50	180	20
Average	—70	40	00	200	

* Data significant at the 5% level of significance.

TABLE 5.—SOYBEAN YIELDS IN BU./ACRE SHOWING ANNUAL RESPONSE TO NITROGEN SOURCES.

Treatment	1950	1951	1952	1953	Average
$NaNO_3$	12.2	13.2	21.6	21.8	17.2
Urea	12.0	13.2	22.0	22.8	17.4
Cyanamid	12.5	15.2	23.2	22.7	18.4
NH_4NO_3	10.8	13.0	22.5	21.7	17.0
$(NH_4)_2SO_4$	11.8	12.4	19.6	21.7	16.4
Duramene	10.8*	15.1	23.2	20.5	17.5
Average	11.7	13.7	22.0	21.9	17.3
L. S. D. 5%	N.S.	N.S.	N.S.	N.S.	N.S.

* $Ca(NO_3)_2$ was substituted for Duramene in 1950.

TABLE 6.—ANNUAL SOYBEAN YIELD RESPONSE TO LIME IN BU./ACRE SHOWING EFFECT OF NITROGEN SOURCES.

Treatment	1950	1951*	1952*	1953*	Average
$NaNO_3$	1.4	4.7	—0.8	2.5	2.0
Urea	6.4	5.3	2.7	1.8	4.1
Cyanamid	4.0	2.8	2.4	1.2	2.6
NH_4NO_3	1.8	0.7	7.0	3.2	3.2
$(NH_4)_2SO_4$	3.7	6.0	1.9	1.0	3.2
Duramene	0.9	4.0	4.6	2.3	3.0
Average	3.0	3.9	3.0	2.0	3.0

* Lime response significant at the 5% level of significance.

acre was applied to the oats, the yields were low. They amounted to approximately 1400 and 1500 pounds of dry weight per acre in 1952 and 1953, respectively. Since the yields were uniform, regardless of treatment, it was doubtful if the oat crop had any effect on the peanut yield response to treatments. For this reason the data are not reported.

Table 5 contains the annual soybean yields for the four years. There was no significant difference for sources of nitrogen any year. The $(NH_4)_2SO_4$ treatment was lowest in 1951 and 1952 and, on the average, was lowest for the four years. Since only 15 pounds of nitrogen from the various sources were applied to legumes, the effect must have been due to application in the planting row and could have been a localized effect on nodulation early in the season. Differences, however, were small. The higher average yields in 1952 and 1953 as compared to those in 1950 and 1951 were due to a change in variety.

The yield data for soybeans showing the relationship between lime and nitrogen sources are shown in Table 6. Significant yield responses resulted in three out of four years where lime was used. The lowest average response from lime resulted when $NaNO_3$ was used as the nitrogen source.

Oat yields were significantly lower in 1952 where Cyanamid and Duramene were used as sources of nitrogen as compared to any other treatment. Yields did not vary significantly as related to treatments in 1951 and 1953. The yield averages indicate that Cyanamid and Duramene were the poorest sources of nitrogen for oats, while the other four sources did not vary significantly among themselves.

The lime responses on oats shown in Table 8 for the various nitrogen sources were inconsistent. Lime was not significant any year, but the lime-treatment interaction in 1951 was significant.

Tables 9 and 10 contain the chemical data from composite 0″ - 6″ samples taken after the experiment was terminated. Those determinations which were affected by sources of nitrogen are reported in Table 9. Each value is an average of two lime levels and three replications. These data indicate that the $(NH_4)_2SO_4$ and NH_4NO_3 treated soils contained significantly less total nitrogen than the others. The pH data show that the $NaNO_3$ and Cyanamid treated soils had the highest pH while the $(NH_4)_2SO_4$ treated soil had the lowest pH. Calcium was significantly higher on the Cyanamid treated plots and the lowest on the $(NH_4)_2SO_4$ treated plots. The $NaNO_3$ and Duramene treated soils had the highest level of K_2O and the Cyanamid treated soil was higher than that treated with $(NH_4)_2SO_4$.

Table 10 contains data of those determinations for which the lime effect was highly significant. The data are averages of three replications and 6 treatments. They show that liming with dolomite increased significantly the potash, calcium and magnesium in the top 6 inches of soil and gave a pH differential of one unit.

Phosphorus extracted with Bray's strong solution (0.03N NH_4F in .1N HCl, 10 of extractant to one of soil) and organic matter by the Walkley-Black Method were not affected significantly by liming or sources of nitrogen. The average phosphorus level was 400 pounds per acre of P_2O_5 and the organic matter was 3.25%.

TABLE 7.—Oat Yields in Bu./Acre Showing Annual Response to Nitrogen Sources.

Treatment	1951	1952	1953	Average
$NaNO_3$	64.5	67.6	41.0	57.7
Urea	61.2	67.9	38.4	55.8
Cyanamid	57.7	50 9	40.0	49.7
NH_4NO_3	61.9	67.4	43.4	57.6
$(NH_4)_2SO_4$	61.2	73.4	42.6	59.0
Duramene	67.0	47.2	35.2	49.8
Average	62.2	62.4	40.1	54.9
L. S. D. 5%	N.S.	10.5	N.S.	N.S.
1%		15.0		

TABLE 8.—Annual Oat Yield Response to Lime in Bu./Acre Showing Effect of Nitrogen Sources.

Treatment	1951*	1952	1953	Average
$NaNO_3$	—4.5	11.9	—1.3	2.0
Urea	—3.3	—6 8	1.4	—2.9
Cyanamid	2.4	2.0	—5.5	—0.4
NH_4NO_3	2.4	4.4	2.3	3.0
$(NH_4)_2SO_4$	—3.9	0.3	2 8	—0.3
Duramene	—6.7	—12.9	—3.3	—7.6
Average	—2.3	0.1	—0.6	—1.0

* The lime-treatment interaction was significant at the 5% level of probability.

TABLE 9.—Chemical Data from Final Soil Samples, Showing Effect of Nitrogen Sources.

	pH	Pounds per Acre		
		Total N	Ca	K_2O
$NaNO_3$	5.8	1360	660	250
Urea	5.7	1400	610	220
Cyanamid	5.8	1430	820	240
NH_4NO_3	5.7	1340	600	220
$(NH_4)_2SO_4$	5.6	1290	470	200
Duramene	5.7	1450	670	260
L. S. D. 5%	0.1	100	30	30
L. S. D. 1%	0.2	N S.	40	40

TABLE 10.—Chemical Data from Final Soil Samples Showing Effect of Lime.

	Limed	Unlimed
pH	6.2	5.2
Ca (pounds per acre)	1050	230
K_2O (pounds per acre)	260	210
Mg (pounds per acre)	360	80

SUMMARY

Six sources of nitrogen; $NaNO_3$, urea, Cyanamid, NH_4NO_3, $(NH_4)_2SO_4$ and Duramene were tested on a three-year rotation with and without dolomitic lime. The rotation consisted of oats for grain followed by soybeans the first year, oats turned down followed by peanuts the second year and lupine plowed down followed by corn the third year. The soil on the experimental site was predominantly Red Bay fine sandy loam.

No one source of nitrogen was consistently superior or inferior to the remaining sources tested as far as the yield data of the cash crops in the rotation were concerned. Chemical data on soil samples indicated however that $(NH_4)_2SO_4$ decreased pH, total nitrogen, calcium and potash.

Two and one-half tons of dolomitic lime improved availability of most nitrogen sources on corn. The yield increase for lime in the presence of $NaNO_3$ and $(NH_4)_2SO_4$ was 5.4 and 1.3 bushels per acre, respectively. The yield increases for lime for the remaining sources were between these values.

One ton of dolomitic lime was not sufficient for peanuts, but when the additional 3300 pounds per acre was applied yield increases amounted to 200 pounds per acre.

ACKNOWLEDGMENTS

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EFFECT OF TIME OF APPLICATION, RATE AND SOURCE OF NITROGEN ON CORN GROWN ON NORFOLK LOAMY FINE SAND

L. G. Thompson, Jr., and W. K. Robertson*

INTRODUCTION

Most of the corn grown in North Florida is sidedressed with nitrate of soda, ammonium nitrate, or anhydrous ammonia. During the last few years farmers have used from 40 to 80 pounds of nitrogen per acre. Because large quantities of nitrogen are used on corn in North Florida, this investigation was conducted to determine the effect of time of application, rate and source of nitrogen on corn yields and on soil fertility.

EXPERIMENTAL PROCEDURE

Field plots 12 x 80.6 ft. were set up in randomized blocks using three sources of nitrogen, three rates of application, and four replications. The corn rows were 36 inches apart, with 17- and 13-inch spacing in the drill giving approximately 10,000 and 13,000 stalks per acre, respectively. The sources of nitrogen used were anhydrous ammonia, ammonium nitrate and nitrate of soda. Two times of application were used for anhydrous ammonia and one time for the other sources. During the five years of the test, the plots were moved from one area to another to simulate rotation conditions.

TABLE 1.—The Chemical Composition of the Areas Used During the Five Years of the Experiment.

Area	Depth Inches	pH	Pounds per Acre			
			Ca	K_2O	Mg	(Bray P_2O_5)
No 1	0-6	4.99	104	20	115	61
	6-12	5.15	83	18	80	34
	12-18	5.16	147	26	125	34
	18-24	5.28	171	29	296	38
No. 2	0-6	4.60	56	73	48	118
	6-12	4.76	48	58	80	34
	12-18	4.86	107	50	149	30
	18-24	5.04	208	32	243	30
No. 3	0-6	5.22	168	44	72	107
	6-12	5.08	234	46	116	69
	12-18	5.43	394	50	164	57
	18-24	5.56	430	30	240	69

* Soils Chemist, North Florida Station and Assistant Chemist, Main Station, respectively.

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Table 1 shows the chemical composition of three areas used during the 5 years of the experiment. Area No. 1 was used in 1951, 1953 and 1954, area No. 2 in 1952 and area No. 3 in 1955. The surface soil of area No. 3 was highest in calcium and pH, and area No. 2 was lowest; otherwise the fertility of the three areas was about the same.

Dixie 18 corn was planted for the five years of the experiment. Soil samples were taken to study the changes brought about in the soil. All plots received a basic fertilizer treatment of 600 pounds of 0-14-10 fertilizer per acre.

RESULTS

The effect of time of application, rate and source of nitrogen on corn grown on Norfolk loamy fine sand is shown in Table 2.

The monthly and annual rainfall in inches at the North Florida Experiment Station for the years 1951 to 1955 is given in Table 3.

In 1951, when rainfall was high; increasing anhydrous ammonia from 40 to 80 pounds per acre when applied at planting time increased the yield of corn 5.8 bushels per acre. This is more than enough corn to pay for the extra 40 pounds of nitrogen. When anhydrous ammonia was applied at knee high, the increase was 4.4 bushels per acre which would also pay for the extra nitrogen. The 40-pound rate of ammonium nitrate and nitrate of soda gave as good yields as higher rates.

In 1952, the corn followed lupine turned under for green manure and the season was dry. Since the lupine supplied enough nitrogen for a 40-bushel crop of corn, additional nitrogen did not increase corn yields.

In 1953, when rainfall was more evenly distributed (Table 3), 40 pounds of nitrogen from any of the three sources of nitrogen gave significant increases in yield. Increasing nitrogen from 40 to 80 pounds per acre increased corn yields 5.3 bushels for ammonium nitrate, but not for the other sources.

In 1954, a dry year, the yield of corn was low. Increasing nitrogen from 0 to 40 pounds per acre gave highly significant increases in the yield of corn, but further increments gave no response.

In 1955, the weather was dry and the corn followed a crop of soybeans, which added considerable fertility to the soil. Increasing the rate of nitrogen from 0 to 40 pounds per acre, gave about a 4.4 bushel increase for anhydrous ammonia which was nearly significant. Added nitrogen above 40 pounds per acre gave very small increases in yield.

These results indicate that on the more fertile soils where a good rotation is practiced and cover crops are turned under for green manure, 40 pounds of nitrogen is probably the most economical rate to use. On poor soils where corn is grown continuously and no green manure crops are turned under, 60 to 80 pounds of nitrogen may be applied profitably.

In another 3-year rotation experiment with green manure crops turned under, it was found that increasing the rate of nitrogen from 21 to 42 pounds per acre gave a significant increase in the yield of corn in some years. However, a second increase in nitrogen from 42 to 63 pounds per acre gave only a slight increase which was not significant. These results show that the variation in rainfall from year to year has a much greater influence on the yield of corn than increasing the rate of nitrogen above 40 pounds per acre.

TABLE. 2.—Effect of Time of Application, Rate and Source of Nitrogen on pH, Soil Nitrogen, and on Corn Grown on Norfolk Loamy Fine Sand.

Fertilizers*			Corn Spacing in Row Inches	Corn, Bushels per Acre						4 Months After Application of Nitrogen for 1955	
Nitrogen Source	Lbs./Acre Nitrogen	Time Applied		1951	1952	1953	1954	1955	Average	pH	Total Nitrogen Lbs. per Acre
Anhydrous	40	At planting time	17	65.4	43.6	63.5	40.0	53.2	53.1	5.40	1020
Ammonia	80	At planting time	17	71.2	40.2	60.8	39 0	53.6	53.0	5.39	1060
Anhydrous	160	At planting time	17	68 2	36.5	59.7	42.1	56.5	52.6	5.29	1100
Ammonia	160	At planting time	13	64 1	40.0	69.7	38.4	55.3	53.5	5.31	1280
Anhydrous	40	At knee high	17	64.3	37.8	63.3	44.1	53.7	52.6	5.39	1080
Ammonia	80	At knee high	17	68.7	39.6	64.3	45.8	53.5	54.4	5.40	960
Anhydrous	160	At knee high	17	64.8	39.5	57.3	41.3	56.4	51.9	5 39	1160
Ammonia	160	At knee high	13	66.1	36.5	70.1	39.2	53.6	53.1	5.44	920
Ammonium	40	At knee high	17	67 2	39.7	60.9	42.3	52.0	52.4	5.28	960
nitrate	80	At knee high	17	67 5	38.6	66.2	44.6	54.6	54.3	5.28	1010
Ammonium	160	At knee high	17	67.5	38.5	60.6	42 5	55.7	53.0	5.20	1160
nitrate	160	At knee high	13	65.4	37.2	63.1	39.4	54.4	51.9	5.23	930
Nitrate of	40	At knee high	17	65.5	45.8	64.8	45.2	51.5	54.6	5.57	990
Soda	80	At knee high	17	67.4	39.7	59.2	40 1	53.0	51.9	5.58	970
Nitrate of Soda	160	At knee high	17	67 8	38.7	63.4	44.6	54.2	53.7	5.76	1130
0	0		17	—	40 4	49.2	28.7	49.1	41.9	5.43	1010
		L. S. D. 5%		not sig.	not sig.	8.8	5.4	not sig.		0.20	
		L. S. D. 1%				11.9	7.3			0.27	

* All plots received a basic application of 600 pounds per acre of 0-14-10.

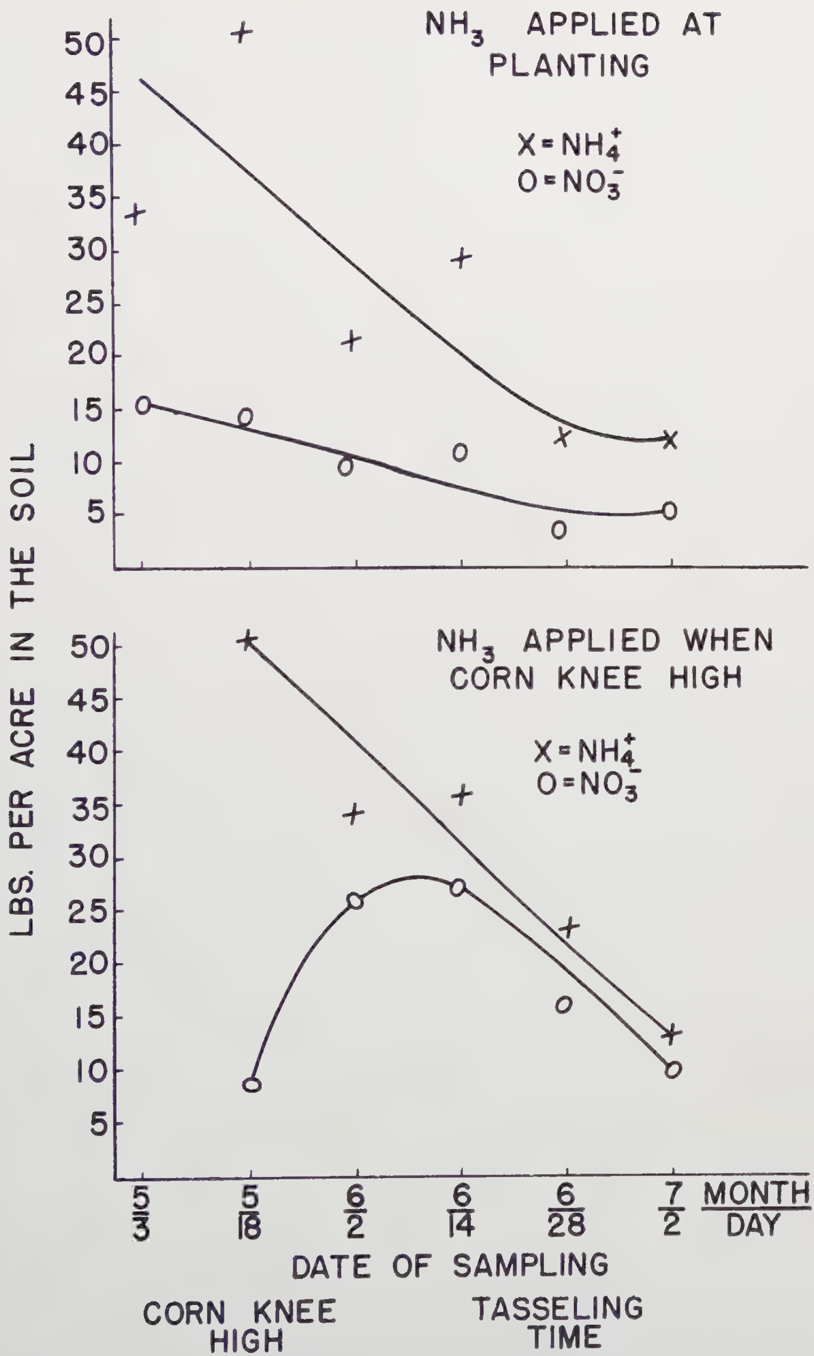

Figure 1.—Effect of time of application on ammonium and nitrate nitrogen in the soil at sampling time.

Increasing nitrogen from none to 40 pounds per acre increased the yield of corn 10 to 12 bushels for a 5-year average. For all sources and rates of nitrogen above 40 pounds, there was only a 2-bushel variation in yield.

TABLE 3.—MONTHLY AND ANNUAL RAINFALL IN INCHES AT THE NORTH FLORIDA EXPERIMENT STATION.

Month	1951	1952	1953	1954	1955
January	1.59	1.47	2.96	2.39	4.04
February	1 63	8.30	4.98	2.26	1.78
March	10.28	5.25	1.68	2.27	0.93
April	2.06	4.06	6.73	2.16	8.32
May	8.02	2.75	1 60	1.97	2.21
June	3.88	3.83	6.92	2.34	1.09
July	4 18	2.52	8.29	4.14	11.29
August	4.84	6.59	1.82	3.22	4.06
September	3.54	5.76	7.13	3.44	1.27
October	1.69	0.50	1.62	1 46	3.12
November	6.65	1.19	3.25	2.43	
December	7.76	2.17	10.10	1.94	
Total	56.12	44.39	57.08	30.02	

In 1953, decreasing the spacing of corn plants in the row from 17 inches to 13 inches gave a significant increase in the yield of corn for anhydrous ammonia, but only a slight increase for ammonium nitrate.

The effect of nitrogen sources on the pH in the soil profile is given in Table 4. Ammonium nitrate slightly lowered the pH in the surface soil, while nitrate of soda raised the pH to 6.0. Anhydrous ammonia slightly raised the pH two months after it was applied, but four months after application when the ammonia was nitrified the pH was about the same as the check. All the sources of nitrogen slightly lowered the pH in the subsoil.

TABLE 4.—THE EFFECT OF NITROGEN SOURCES ON THE pH IN THE SOIL PROFILE TWO MONTHS AFTER APPLICATION OF NITROGEN FOR 1955.*

Depth Inches	Check	pH of the Soil		
		NH_4NO_3	$NaNO_3$	Anhydrous Ammonia
0-6	5.2	4.9	6.0	5.6
6-12	5.0	4.8	4.9	5.1
12-18	5.4	5.0	5.0	5.0
18-24	5.6	5.2	5.2	5 2
24-30	5.6	5.1	5.2	5.2

* Samples were taken approximately in the area where fertilizer was applied.

Four months after the nitrogen had been applied (Table 2), the pH was higher in the nitrate of soda plots and lower in the ammonium

nitrate plots than in the check. However, the pH of the anhydrous ammonia plots was about the same as the check plots. There was no significant difference in the level of nitrogen left after the corn was mature regardless of the rate or time of application.

The effect of time of applying anhydrous ammonia on the ammonium and nitrate nitrogen in the soil for 1951 is shown in Figure 1.

Corn was planted April 2. On those plots, where ammonia was applied at planting time, the first samples were collected May 3. On the plots, which were treated at the knee-high stage of growth, the first samples were collected May 18. This gave a four- and two-week interval, respectively, between application time and the first sampling date. Thereafter, samples were taken at two-week intervals approximately. Samples were composites of six groups of five one-inch borings six inches deep at two-inch intervals across the ammonia injector row. They were dried rapidly and analyzed within one week of the sampling date.

Anhydrous ammonia applied at planting time gave steadily decreasing levels of ammonium and nitrate nitrogen during the sampling period, May 3 to July 12. Anhydrous ammonia applied when the corn was knee high gave steadily decreasing level of ammonium nitrogen, while nitrate nitrogen reached a maximum early in June. Although the later time of application gave a nitrate distribution apparently more favorable to the corn crop, there was no consistent difference in yield.

SUMMARY

The 5-year average yield of corn was about the same for all sources of nitrogen used. Therefore, the most economical source of nitrogen would be the one that costs the least per pound of nitrogen. Because anhydrous ammonia does not leach out of the soil until it is nitrified, it may be applied at planting time or when the corn is knee high with equally good results. Since the nitrate ion leaches readily out of the soil, sodium nitrate and ammonium nitrate should probably be applied when the corn is knee high. Where a good rotation is practiced and cover crops are turned under for green manure, 40 pounds of nitrogen is probably the most economical rate to use. On poor soil where corn is grown continuously and no green manure crops are turned under, 60 to 80 pounds of nitrogen may be applied profitably.

NITROGEN FERTILIZATION OF ST. AUGUSTINE GRASS GROWN ON DAVIE FINE SAND

F. T. Boyd*

The rapid growth of the cattle industry in South Florida and the phenomenal urban housing development of the coastal areas have created the need for higher pasture yields to compensate for the rise in land values. Proper water control and heavy fertilization of adapted forage plants are prerequisites to the economic use of these areas for grazing purposes.

Several tropical grasses have been used to establish improved pastures in Florida. St. Augustine grass (*Stenotaphrum secundatum*) on peat soils has consistently produced highest beef gains on grazing animals(1). Its dense sod, ability to withstand heavy grazing, resistance to light frosts, and high nutritive value have increased its popularity for grazing purposes. It is also the predominant grass in lawns of South Florida.

Most fertility studies on this grass have been conducted on the peat or muck soils of the Everglades—consequently there is little data available on the sandy mineral soils of the coastal region. In order to obtain the desired information, two general experiments were conducted at Ft. Lauderdale: (A) to determine the best N-P-K fertility ratio for St. Augustine grass, and (B) to determine the effects of various rates and frequencies of nitrogen fertilization.

EXPERIMENTAL

On June 30, 1953 experiments were initiated to study the N-P-K fertility requirements of St. Augustine grass on Davie fine sand.

Experiment A: Fertility Ratio Study

Twenty treatments were arranged in quadruplicate in four randomized blocks. These treatments are listed in Table I. Each plot was 1/200 acre in size. All plots received an initial application of a mixture of minor elements derived from Es-Min-El [1] at 50 pounds per acre. Major plant nutrients were applied in three applications per year. One-fourth of the total annual treatment was applied June 30, 1953; one-half was applied November 5, 1953; and one-fourth applied March 10, 1954. In the second year of the experiment, the quantity of nitrogen was doubled for each treatment. Applications of fertilizer were made July 17, 1954, Dec. 7, 1954, and March 1, 1955 at ¼, ½, and ¼ the annual rate, respectively.

Plots were harvested August 5, Sept. 24, Dec. 1, March 5, April 16, May 19, and June 10, the first year, and July 13, Aug. 27, Oct. 4, Nov. 30, March 1, March 30, May 10, and June 10, the second year. The experimental area was subsurface-irrigated by maintaining water levels in ad-

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* Associate Agronomist, Everglades Expt. Station, Plantation Field Laboratory, Ft. Lauderdale, Florida.

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[1] Es-Min-El contained 6.25 percent CuO, 12.90 percent MnO, and 6.22 percent ZnO.

joining ditches at heights sufficient to give ground water tables of approximately 18" - 24" below the land surface. Soil samples were taken from each plot June 28, 1955 for chemical analysis. Grass samples were taken for dry matter and protein analysis Sept. 24, Dec. 1, 1953, and May 19 - 20, 1954.

TABLE I.—EFFECT OF VARIOUS FERTILITY RATIOS ON GROWTH OF ST. AUGUSTINE GRASS—JULY 1, 1953 - JULY 1, 1955.

Rates Applied Each Year*	Tons Green Forage per Acre	
	1953-54	1954-55**
$N - P_2O_5 - K_2O$		
Control (minor elements only)	2.73	2.82
30 - 30 - 30	3.39	4.94
60 - 30 - 30	4 40	5 76
60 - 30 - 60	3.78	8.26
60 - 60 - 60	4.03	8.51
90 - 30 - 60	4.21	8.12
90 - 60 - 60	4.21	9.84
90 - 60 - 90	4.51	9.19
120 - 60 - 60	6.92	12.02
120 - 60 - 90	7.52	12.31
120 - 60 - 120	6.59	11.64
120 - 90 - 90	6.09	13 86
180 - 60 - 120	8.68	15 67
180 - 60 - 180	8 01	17.17
180 - 120 - 120	8.11	17 62
180 - 120 - 180	7.88	17.64
240 - 60 - 120	9.68	19.16
240 - 60 - 180	11.14	18.53
240 - 120 - 180	10.62	21.94
240 - 180 - 180	10.97	21.96
L. S. D.—5% level	0.60	2.20
L. S. D.—1% level	0 80	2.91

* Fertilizer applied in three applications each year.
** Rates of nitrogen doubled in 1954-55.

EXPERIMENT B: RATE AND FREQUENCY OF NITROGEN FERTILIZATION

Six treatments were arranged in a Latin Square of 36 plots, each plot 1/200 acre in size. Mineral fertilizers consisting of superphosphate, muriate of potash, and minor elements contained in Es-Min-El were applied over the test area as follow: 0-60-60[2] with 50 pounds of Es-Min-El June 30, 1953; 0-60-60 Sept. 24, 1953; 0-60-60 with 50 pounds Es-Min-El Aug. 24, 1954; and 0-60-60 Dec. 7, 1954. All nitrogen in both experiments was applied as ammonium nitrate. Each fertilization was made after grass cuttings had been removed. Nitrogen was applied at 30 and 60 pounds N per acre, twice, four times, and eight times a year, giving total yearly treatments ranging from 60 pounds to 480 pounds N per acre.

[2] 0-60-60 is equivalent to 500 lbs. 0-12-12 per acre.

RESULTS

Experiment A: Fertility Ratios

The St. Augustine grass responded immediately in both growth and color to complete fertilizer mixtures. During the first year of the experiment, the heaviest treatment included 240 pounds nitrogen per acre per year. The highest yield obtained with this rate, as shown in Table I, was 11.14 tons of green forage per acre where a 4-1-3 fertilizer ratio was used. During the second year, by doubling the nitrogen content of each treatment, the heaviest treatments contained 480 pounds N per acre. The highest yields obtained after increasing the nitrogen was 21.96 tons green forage using a 16-6-6 fertility ratio and 21.94 tons from the 16-4-6 ratio. Thus, by increasing the maximum nitrogen rates from 240 pounds to 480 pounds nitrogen per acre, the yield was increased over 10 tons per acre or 97 percent. The amount of plant nutrients which appeared most effective was 480 N—120 P_2O_5—180 K_2O, or 3,000 pounds of a 16-4-6 formula containing minor elements. The control plots (with minors only) produced 2.82 tons of green forage per acre or about 1/8 of that produced by the best treatment.

Experiment B: Rate and Frequency of Nitrogen Fertilization

St. Augustine grass has shown an almost straight line positive response to nitrogen fertilization within the limits of this experiment. Table II shows there were no significant differences attributable to frequency of application. Nitrogen at 240 pounds per acre produced as much grass when applied in four applications as when the same amount of nitrogen was divided into eight applications. Similarly, nitrogen at 120 pounds per acre produced as great a response in two applications as when split into four treatments.

TABLE II.—Effect of Rate and Frequency of Nitrogen Fertilization on Yield, Dry Matter, and Protein Contents—July 1, 1953 - July 1, 1955.

Total Nitrogen per Acre per Year (Pounds)	Frequency of Application	Average Yield per Year, Tons Green Forage per Acre	Dry Matter (Percent)	Protein (Percent)
60	30 lbs. twice a year	8.56	30.2	9.0
120	60 lbs. twice a year	11.25	28.8	9.3
120	30 lbs. 4 times a year..	11 10	30.4	8.4
240	60 lbs. 4 times a year..	14.80	27.5	9.3
240	30 lbs. 8 times a year..	15.37	26.4	11.3
480	60 lbs. 8 times a year..	20.30	26.0	11.7

L. S. D.—5% level—0.90.
L. S. D.—1% level—1.24.

St. Augustine grass production ranged from an average yield of 8.56 tons green forage per acre when a total of 60 pounds nitrogen was used, to an average of 20.31 tons per acre when 480 pounds nitrogen was applied during the year.

From the data in Table II it is apparent that higher rates of nitrogen fertilization increased the protein content but decreased the dry matter percentage of the forage as harvested.

TABLE III.—Results of Soil Tests.

Total Nitrogen per Year	pH	Water Soluble P*	Soluble in N/2 Acetic Acid K*	Ca*	Mg*
Before Fertilization and Cropping					
	6.00	0.6	27	1250	141
After 2 Years Fertilization and Grass Harvest					
60 lbs. N	5.67	2.0	32	842	47
120 lbs. N	5.55	1.9	28	847	51
240 lbs. N	5.57	1.4	34	978	45
240 lbs. N	5.61	2.7	36	973	41
480 lbs. N	5.52	2.1	27	940	37

* Expressed as pounds per acre of P, K, Ca, and Mg.

Effect of Fetilization and Cropping on Soil pH and Nutrient Availability

Soil tests for pH and availability of phosphorus, potassium, calcium. and magnesium were made on soil samples collected from the experimental area before any fertilizer was applied in 1953. A second series of samples were taken after two years of fertilization and grass harvesting.

These data show a reduction in soil pH and in calcium and magnesium contents. No significant difference is apparent in such reduction between the various rates of nitrogen fertilization. Evidently calcium and magnesium in irrigation water were sufficient to replace most of that removed in grass cuttings.

SUMMARY

Progressive growers recognize that greater pasture yields are necessary to meet the crisis produced by rising land values and the price of commercial feeds. Heavier nitrogen fertilization has been shown to be the key to increased grass production. St. Augustine grass fertilized three times each year with a 16-4-6 fertilizer at the rate of 1,000 pounds per application produced nearly 22 tons of green forage per acre. Under favorable grazing conditions, 1500 pounds of 16-4-6 fertilizer should give comparable results, when applied in three applications.

ACKNOWLEDGMENTS

The author is indebted to Drs. C. T. Ozaki and A. E. Kretschmer, Jr., under whose supervision analyses reported in Tables II and III were made at the Everglades Station, Belle Glade. An expression of appreciation is also due Drs. G. M. Volk and N. Gammon of the Soils Department, Florida Agricultural Experiment Station, for suggestions in setting up treatment levels for nitrogen.

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NITROGEN IN CELERY FERTILIZATION

P. J. WESTGATE*

Celery is a major vegetable crop in the Sanford area where for the past fifty years, it has been grown primarily on Leon fine sand. It is a heavy feeder on nitrogen, one of the three major plant nutrients which has been used in large quantities in the commercial celery fields of the area. Without the addition of fertilizer containing nitrogen, it is practically impossible to grow a marketable crop.

This report is primarily a review of the literature(1) (2) (3) and (4) with the inclusion of certain additional unpublished data(5) from recent tests covering two phases of nitrogen fertilization of this crop, namely, the amount of nitrogen per acre applied versus yield, and the use of nitrate nitrogen versus ammonia nitrogen.

AMOUNTS OF NITROGEN PER ACRE VERSUS YIELD OF CELERY

Reports prior to 1930(2) showed marked increases of marketable celery with fertilizer increases up to five tons per acre of a 6(NH_3) - 6(P_2O_5) - 6(K_2O) fertilizer. The sources of the fertilizer ingredients were as follows: phosphoric acid from superphosphate; potash from sulfate of potash; nitrogen from 1/6 each ammonium sulfate, sodium nitrate, cottonseed meal, fish scrap, tankage, and dried blood. A summary of data from certain of these early experiments is given in Table 1.

TABLE 1.—VARIOUS AMOUNTS OF NITROGEN APPLIED PER ACRE AND YIELD OF MARKETABLE CELERY, 1925.

Fertilizer Applied, Pounds per Acre (6-6-6)	Pounds Nitrogen (N) in the 6-6-6	Percent Large Sizes (3 to 6 Dozen per Crate)	Average Yield Marketable Celery (Crates per Acre)
0	0	0	0
1,000	49	0	256
2,000	98	0	383
3,000	148	6	523
4,000	197	38	542
5,000	246	63	612
6,000	295	73	664
8,000	394	80	661
10,000	492	87	727

Early fertilizer ratio experiments with celery(2) showed that a fertilizer mixture containing 6 percent ammonia when used at the rate of 8,000 pounds per acre was about right. Table 2 is a summary of the yield data from several of these experiments in which the nitrogen was derived, ¼ from each of the following: ammonium sulfate, sodium nitrate, cottonseed meal, and fish scrap.

* Associate horticulturist, Central Florida Experiment Station, Sanford.

[1] All nitrogen was reported as ammonia in these early fertilizer formulas.

TABLE 2.—VARIOUS RATIOS OF NITROGEN APPLIED PER ACRE AND YIELD OF MARKETABLE CELERY, 1925.

Group	Percent Ammonia in 8,000 Lbs./A. of Fertilizer	Nitrogen (N) Applied (Pounds per Acre)	Average Yield Marketable Celery (Crates per Acre)
I	2	131	454
II	4	262	584
III	6	394	622
IV	8	525	625
V	10	656	624

Data reported in 1951(3) showed that although four tons per acre of a 5-5-8 [1] fertilizer gave the largest total yield of celery, three tons per acre of the same analysis gave the greatest freedom from disease (black-heart) and the most marketable celery. These results are summarized in Table 3.

TABLE 3.—RELATION OF AMOUNT OF NITROGEN APPLIED PER ACRE TO YIELD OF MARKETABLE CELERY, 1951.

Fertilizer Applied Pounds per Acre (5-5-8)	Pounds Nitrogen (N) in the 5-5-8	Yield of Marketable Celery (Crates per Acre)
0	0	109
2,000	100	513
4,000	200	815
6,000	300	906
8 000	400	844
10,000	500	637

In 1954(4) data from experimental plots again showed a maximum yield of marketable celery from three tons per acre of a 5-5-8 [2] fertilizer as shown in Table 4.

	Percent N
[1] Nitrate nitrogen	1.32
Ammonia nitrogen	1.64
Water soluble organic nitrogen	0.32
Water insoluble nitrogen	1.72
Total nitrogen (N)	5.00

	Percent N
[2] Nitrate nitrogen	2.00
Ammonia nitrogen	1.50
Water soluble organic nitrogen	0.25
Water insoluble organic	1.25
Total nitrogen (N)	5.00

TABLE 4.—RELATION OF AMOUNTS OF NITOGEN APPLIED PER ACRE AND YIELD OF MARKETABLE CELERY, 1954.

Fertilizer Applied Pounds per Acre (5-5-8)	Pounds Nitrogen (N) in the 5-5-8	Yield of Marketable Celery (Crates per Acre)*
0	0	157
2,000	100	513
4,000	200	650
6,000	300	663
8,000	400	563
10,000	500	578

* 55 pound crate, 60 percent packout.

NITRATE NITROGEN VERSUS AMMONIA NITROGEN FOR CELERY

As early as 1924(2) it was shown that there was a marked increase in yields of celery when all nitrate nitrogen from sodium nitrate was used in comparison to all ammonia nitrogen from ammonium sulfate. Fertilizer was applied at the rate of 8,000 pounds per acre as a 6-6-6 mixture containing NH_3, P_2O_5 and K_2O as shown in Table 5.

TABLE 5.—NITRATE NITROGEN VERSUS AMMONIA NITROGEN FOR CELERY, 1924.

Source of Nitrogen	Nitrogen Applied (Pounds per Acre)	Average Yield of Marketable Celery (Crates per Acre)
Ammonium Sulfate	394	286
Sodium Nitrate	394	494

In 1937(1) it was shown that when all the nitrogen was derived from sodium nitrate there was a two-fold increase in marketable celery in comparison to the yield obtained when all the nitrogen was derived from ammonium sulfate. In order to determine if the acidity of the ammonium sulfate was adversely affecting the yield, a third treatment including all nitrogen from ammonium sulfate with lime to neutralize was added to the experiment. As shown in Table 6, there was a marked reduction in yield of celery with ammonium sulfate regardless of whether or not lime was used. Fertilizer was used at the rate of 6600 pounds per acre of a 5-6-8 analysis in this experiment.

In 1955(5) various amounts as well as sources of nitrogen were tested on celery. These results, summarized in Table 7, show that there was a maximum yield of marketable celery with 300 pounds per acre of nitrogen when 40% of the nitrogen was nitrate nitrogen (N), and 60% was ammonia nitrogen (N). At the same time there was a marked increase in yield of marketable celery at 500 pounds per acre of nitrogen when all of the nitrogen came either from sodium nitrate or from calcium nitrate.

TABLE 6.—Nitrate Nitrogen versus Ammonia Nitrogen for Celery, 1937.

Source of Nitrogen	Nitrogen Applied (Pounds per Acre)	Average Yield of Marketable Celery (Crates per Acre)
All nitrogen from ammonium sulfate	330	354
All nitrogen from ammonium sulfate + lime	330	348
All nitrogen from sodium nitrate	330	1047

The all-nitrate nitrogen plots of celery were a normal green color with long, upright stalks and flat, open leaves. The celery receiving larger amounts of ammonia nitrogen were lighter green, and more or less squatty with short down curving petioles, and curled leaves. Such stunted celery plants accompanied by high ammonia in the soil have been observed in commercial fields in the Sanford area, as well as in experimental plots. This trouble appears to be due to an excess of ammonia rather than a lack of nitrate nitrogen. Addition of nitrate nitrogen will not correct the trouble, but warmer weather accompanied by nitrification of ammonia to nitrate relieves the situation. The amount of ammonia nitrogen which a celery plant can best utilize in a fertilizer formula will depend upon factors influencing nitrification. For example, a spring crop of celery would be able to utilize a fertilizer containing more ammonia nitrogen than a winter crop because of the more favorable temperature for nitrification that prevails at that time.

TABLE 7.—Nitrate Nitrogen versus Ammonia Nitrogen for Celery, 1955.

Fertilizer Applied Pounds per Acre (5-5-8)	Pounds Nitrogen (N) from the 5-5-8	Sources of Nitrogen	Yield of Marketable Celery, Crates per Acre*
0	0	0	192
2,000	100	40 percent as NO_3 and 60 percent as NH_3 from ammonium sulfate, ammonium nitrate and sodium nitrate	488
6,000	300		780
10,000	500		698
10,000	500	100 percent from $NaNO_3$	1029
10,000	500	100 percent from $Co(NO_3)_2$	1051

* 55 pound crate, 60 percent packout.

SUMMARY

Celery, a heavy nitrogen feeder, has produced maximum yields of marketable crop on Leon fine sand in the Sanford area by using from 300 to 500 pounds per acre of this element.

Marked increases of marketable celery have been obtained by the use of all nitrate nitrogen, either from sodium nitrate or calcium nitrate, in comparison to equal amounts of nitrogen from ammonium sulfate and ammonium nitrate. The addition of lime to neutralize the acidity of the ammonium sulfate has not corrected the trouble.

Stunted, light celery plants with short, down curving petioles, and curled leaves are characteristic of excessive ammonia nitrogen in the soil. Such plants have been observed in experimental plots and in commercial celery fields in the area that have been heavily fertilized with ammonia nitrogen.

The amount of ammonia nitrogen which celery can tolerate in a fertilizer formula will depend upon soil factors influencing nitrification of ammonia nitrogen to nitrate nitrogen.

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NITROGEN EXPERIMENTS WITH POTATOES AND TOMATOES ON MARL SOILS

John L. Malcolm*

The experiments described in this paper were designed to determine the nitrogen requirements of potatoes and tomatoes on the marl soils of Dade County. In the first of three potato experiments only the nitrogen content of the fertilizer was varied. This experiment was continued for four years to allow time for depletion of nitrogen from the check plot and the accumulation of excessive amounts of the higher rates of application. A test comparing the efficiency of applying nitrogen fertilizer to the soil with applying it to the leaves and the soils with the fungicide spray was run for one year. A further test of the rate of application of nitrogen was run in which the rate of application of phosphorus and potash was varied as well. The rate of application of nitrogen experiment with tomatoes was continued for seven years. Over the time several different sources of nitrogen were tested. To supplement the yield data as a measure of response to treatment, the composition of tomato leaf samples taken from the plots during the last four seasons was determined.

PREVIOUS EXPERIMENTS

Fifield and Wolfe(2) reported several potato experiments with nitrogen on marl soils. The treatments in their experiments were not applied to the same plots over a period of years. They found that maximum yields were obtained with from 45 to 80 pounds of nitrogen per acre and that yields were reduced where the rate of application of nitrogen was increased to 120 pounds per acre. In other experiments they found sulfate of ammonia and urea to be good sources of water-soluble nitrogen but concluded that a portion of the nitrogen in potato fertilizer should be derived from a water-insoluble source.

A series of nitrogen fertilizer rate experiments was run by Skinner and Ruprecht(4) with tomato on marl soils. In their experiments the location of the plots was changed each year. The maximum yields of marketable tomatoes were obtained from plots which received from 99 to 148 pounds of nitrogen. When the rate of application was increased to 198 or more pounds of nitrogen per acre, yields were reduced. They obtained the most satisfactory results from organic sources of nitrogen, with almost as good results where only three-fourths or half of the nitrogen was derived from an organic source.

PRESENT POTATO EXPERIMENTS

The potato experiments described in this paper were conducted at the Sub-Tropical Experiment Station East Glade Farm. The marl soil, the history of the land, and the general cultural procedures followed in

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* Associate Soils Chemist, Sub-Tropical Experiment Station, Homestead.

the experiments were described in detail in a previous paper(3). This land had been farmed for 15 or more years before this experiment was started. It is well drained and the soil becomes very dry during a prolonged dry spell.

An experiment in the 1948-1949 through the 1951-1952 seasons compared a no nitrogen check with low, medium, and high rates of application of nitrogen. The nitrogen was included in a mixed fertilizer applied at the rate of 1500 pounds per acre. The rates of application of nitrogen were 0, 30, 60, and 120 pounds per acre. Three sources of nitrogen were employed. Where nitrogen was applied, the first thirty pounds was derived from sulfate of ammonia, an inexpensive and proved source of the element. The next thirty pounds in the two higher rates of application was derived from tankage. The last sixty pounds of nitrogen in the highest treatment was derived from urea, also a proven source of water-soluble nitrogen on the marl soil. The urea had a sufficiently high nitrogen content to permit the mixing of the high nitrogen fertilizer which could be used at the same rate of application as the low nitrogen mixtures without changing the source of the other elements in the formulation. This experiment was continued without changing plot locations for four years.

Two supplementary experiments were run with nitrogen fertilizers on potatoes. The first in the 1953-54 season compared the effectiveness of banded application of nitrogen fertilizer at planting time with spraying an equal amount of the same source of nitrogen on the foliage along with the fungicide. Fifty pounds of nitrogen per acre was applied. Urea was the only source of nitrogen. Nine sprays were applied. A no nitrogen check was also included in this experiment. All of the plots received a base application of 500 pounds of 0-10-10 per acre.

In the second supplementary experiment, in the 1954-55 season a 5-10-10 fertilizer was applied at three rates of 500, 1000, and 2000 pounds per acre and a 2.5-10-10 was applied at 1000 pounds per acre. The plots fertilized with 2.5-10-10 received only as much nitrogen as those fertilized with 500 pounds of 5-10-10 but twice as much phosphorus and potash. They received as much phosphorus and potash as the plots treated with 1000 pounds of 5-10-10 but only half as much nitrogen.

The cultural practices in the two supplementary experiments were the same as those followed in previous years with two exceptions. In the 1954-1955 experiment the Pontiac, a higher yielding variety, was substituted for the Bliss Triumph which had been grown in all of the previous experiments. The spacing of the seed pieces was reduced from ten inches apart in the row to seven inches, since such closer spacing has been shown to give a profitable increase in yield.

In all of the potato experiments there were no visible symptoms of deficiency or of excess of nitrogen. The vines on all of the plots were uniform in color and growth.

The yield of No. 1 potatoes in the principal experiment are shown in Table 1. Ninety percent of the total yield was No. 1 and there was no difference in grade with treatment. The value reported for each treatment each year is the average of four replicates. The four year average is also presented. The yields are reported in pounds per 1/200 acre plots.

TABLE 1.—Yield of Number 1 Potatoes in Nitrogen Fertilizer Test.
(pounds per 0.005 acre plot)*

Nitrogen Lbs./Acre	Season				Average
	1949	1950	1951	1952	
0	107.6	61.6	85.7	69.0	81.0
30	110.2	61.3	89.2	67.7	82.1
60	101.3	68.1	94.8	71.5	83.9
120	106.8	65.0	94.0	72.1	84.5

* Yield in pounds per plot multiplied by four equals sacks per acre.

There was no statistically significant difference in the yields from the several treatments either in one year or over the four year period. The no nitrogen check plots produced as well in the 1951-1952 season as in the 1948-1949 season. This was true of the high nitrogen plots also. There was no depression of yield at 120 pounds of nitrogen per acre per year. The yields varied from season to season but not from treatment to treatment in one season.

Such a lack of response to nitrogen fertilizer on a mineral soil in a high rainfall area is surprising. It was not the result of generally poor growth which would require little nitrogen. The average yield of 332 sacks per acre compares favorably with the five year average from 1947-1948 through 1951-1952 seasons in Dade County which was 318 sacks per acre(1).

During the course of this experiment the nitrate content of soil samples taken every two weeks from an unfertilized area adjoining the potato plots was determined by Mr. M. H. Gallatin.[1] Between rains the nitrate nitrogen accumulated in this soil. The range during growing seasons, from November to March, was 3.8 - 59.0 p.p.m. in 1948-1949, 1.8 - 13.1 in 1949-1950, 3.2 - 69.5 in 1950-1951, and 4.7 - 35.0 in 1951-1952. The average nitrate nitrogen content of the soil during these four seasons was 25.0, 7.3, 21.8, and 17.9, respectively. In two of the four years the nitrate nitrogen content of the unfertilized soil equalled the nitrogen applied in the highest nitrogen fertilizer. The best yields were obtained in 1948-1949 and 1950-1951 seasons when the soil had the most nitrate nitrogen. Since there was no significant yield response in any season to the nitrogen fertilizer it is probable that the same factors which promoted the formation of nitrate in the soil also promoted plant growth. The soil was capable of releasing sufficient available nitrogen for maximum growth in all four growing seasons.

In the four years the experiment was conducted the available nitrogen supply in the soil was adequate to meet the requirements of Bliss Triumph potatoes without the use of nitrogen for fertilizer. No damage resulted from the use of 120 pounds of nitrogen per acre. At the end of four years there was no accumulative effect of the treatments.

In the first supplementary experiment in which urea nitrogen was applied to the soil and to the foliage in combination with the fungicide

[1] Personal communication.

there was no significant difference in yields. The plots which received the urea mixed with the other fertilizer produced 428 sacks per acre, the plots which received the urea with the fungicide produced 425 sacks per acre and the no nitrogen check plots produced 419 sacks per acre. A difference of 11.4 sacks per acre was required for significance at the 0.05 level. In this experiment the available soil nitrogen was sufficient for potatoes. Applying the nitrogen directly to the leaves of the potato plants was not advantageous where the soil supplied the nitrogen required for optimum growth.

In the second supplementary experiment, the yield increases from phosphorus and potash were significant at the 0.05 level but the difference in yield between the two nitrogen levels was not. Plots receiving 25 pounds of nitrogen per acre produced 371 sacks of No. 1 potatoes and those plots receiving 50 pounds of nitrogen per acre produced 385 sacks. A difference of 50 sacks per acre was required for significance in this experiment.

In all three of these experiments the soil supplied the nitrogen required by the potatoes. From these results it is apparent that the nitrogen is being supplied to this soil by natural means. The soil has been farmed too long for the oxidation of the original organic matter to supply nitrogen in amounts sufficient for the growth of potatoes. Although a cover crop of sesbania has been used on this land during the summer months, the nodule development was too poor to supply such a large amount of nitrogen. The results on these plots and observation throughout the area suggest that nonsymbiotic fixation of atmospheric nitrogen is taking place.

PRESENT TOMATO EXPERIMENT

The experiment to determine the nitrogen requirements of tomatoes on marl soil was conducted on the Sub-Tropical Experiment Station Highlands Farm. The description of the soil, the history of land use, the water control system, and the general cultural practices were described in a previous paper(3). Even with drainage this deep marl stays wet during the major portions of most crop seasons. Although in the later years the plants were set in December, rather than in January, the year of the harvest will be used to designate the season. The Grothen Globe variety, planted in 1949 and 1950, was replaced by the Homestead, which is wilt resistant.

Each plot received the same amount of nitrogen fertilizer each year from 1949 through 1955. The total amount of nitrogen applied to all of the plots was increased in 1952 and 1953 by the application of cyanamid for the control of sclerotiniose. The highest nitrogen plot was not added to the test until 1954 so that there are only two year's results from this treatment.

In 1949, 1950, and 1951 the treatments were 0, 40, 80, and 160 pounds of nitrogen per acre. In 1952 a broadcast application of cyanamid before planting supplied 170 pounds of nitrogen per acre and the plots received a total of 170, 210, 250, and 330 pounds per acre. In the 1953 season a smaller amount of cyanamid was used and the total amount of nitrogen applied to the plots was 80, 120, 160, and 240 pounds per acre. Since the sclerotiniose ceased to be a problem on the plot area, cyanamid was

not used in the 1954 and 1955 seasons. Plots receiving 320 pounds of nitrogen per acre were included in the experiment in 1954 and 1955.

During the first five years the nitrogen was included in a mixed fertilizer applied at the total rate of 2000 pounds per acre. The same mixture was used for planting and the three side dressings on each treatment. The mixtures were made so that all of the plots except the checks received 40 pounds of nitrogen per acre from sulfate of ammonia, the 80 and 160 pound nitrogen plots received forty additional pounds of nitrogen from tankage and the balance of the nitrogen for the 160 pound plot was derived from urea.

Some changes were made in the quantity of the other elements applied from year to year as the results of other experiments became available. The rate of application of potash was increased from 100 to 200 pounds of K_2O per acre in 1952 and 1953 and from 200 to 300 in 1954 and 1955. After the first four years, no more magnesium was used and the manganese was supplied with the fungicide rather than in the fertilizer.

In 1954 ammonium nitrate was used as the sole source of nitrogen. In the 1955 season sulfate of ammonia and urea were used as nitrogen sources. All of the nitrogen applied in the 40 and 80 pound treatments was derived from sulfate of ammonia. In the 40 pound treatment all of the nitrogen was applied at planting time. Half of the nitrogen was applied at planting time and half at the first sidedressing in the 80 pound treatment. Where 160 and 320 pounds of nitrogen per acre were applied, half of the nitrogen was from sulfate of ammonia and half from urea. The ammonium sulfate was applied at planting and in the first sidedressing and the urea was applied at the second sidedressing.

The phosphorus for these plots was all applied at planting time but the potash was applied at planting and in two sidedressings.

The tomatoes were picked either three or four times each season. The fruit was separated into marketable and cull grades. The values reported in Tables 2 and 3 are the average yields from all of the replicates of each treatment each year.

The effects of the treatments on chemical composition of the plants were also determined. Leaf samples were taken only the last four years of the experiment. The leaf sampling procedure and the methods of

TABLE 2.—Yield of Marketable Tomatoes in Nitrogen Fertilizer Test. (pounds per 0.01 acre plot) *

Nitrogen Lbs./A.	Season							Average‡
	1949	1950	1951	1952**	1953†	1954	1955	
0	60.7	39.2	98.4	103.7	66.8	32.0	98.6	65 8
40	85.5	63.0	133.6	107.8	110.1	84.6	144.2	102.2
80	103.1	76.3	146.3	97.8	118.2	130 0	175.0	126.1
160	122.8	53.3	170.2	101.3	116.4	168 0	226.0	148.1
320	....	....	....	....	....	163.0	201.5	....

* Yield in pounds per plot multiplied by 1.886 equals bushels per acre.
** Cyanamid supplied an additional 170 pounds of nitrogen per acre.
† Cyanamid supplied an additional 80 pounds of nitrogen per acre.
‡ 1952 and 1953 omitted.

TABLE 3.—YIELD OF TOMATOES OF ALL GRADES IN NITROGEN FERTILIZER TEST.
(pounds per 0.01 acre plot)*

Nitrogen Lbs./A.	Season							Average‡
	1949	1950	1951	1952**	1953†	1954	1955	
9	119.8	78.4	137.0	192.1	88.2	47 6	129.5	102.6
40	157.2	126.0	194.8	212.1	204.8	112.8	191.2	156.5
80	196 0	152.6	224.0	192.1	222 8	172.5	240.8	197 4
160	231.5	106.6	247.8	198.4	233.4	231.3	311.9	226.2
320	----	----	----	----	----	223.4	299.0	....

* Yield in pounds per plot multiplied by 1.886 equals yield in bushels per acre.
** Cyanamid supplied an additional 170 pounds of nitrogen per acre.
† Cyanamid supplied an additional 80 pounds of nitrogen per acre.
‡ 1952 and 1953 omitted.

determining phosphorus, potassium, calcium, magnesium and manganese are outlined in a previous paper(3). Nitrogen was determined by the Kjeldahl method. The leaf samples were taken at the last picking as a precaution against the spread of virus diseases. The results of these analyses are reported in Table 4.

The results of the tomato experiment were quite different from those in the potato experiment. The appearance of the planting, the yield of fruit, and the chemical composition of the leaves all changed with the treatments.

TABLE 4.—COMPOSITION OF TOMATO LEAVES FROM NITROGEN TEST 1952-1955.
(percent dry weight)

Season	Nitrogen Applied		Composition					
	Fertilizer Lbs./A.	Cyanamid Lbs./A.	N	P	K	Ca	Mg	Mn
1952	0	170	3.33	0.27	2.6	2.2	0.66	0.017
	40	170	3.62	0.28	2.5	2.1	0.67	0.016
	80	170	3.65	0.27	2.7	2.2	0.68	0.017
	160	170	3.98	0.26	2.5	2.1	0.66	0.017
1953	0	80	3.16	0.33	2.7	3.3	0.55	0.016
	40	80	2.90	0.31	2.6	3.7	0.53	0 017
	80	80	3.09	0.32	2.6	3.8	0.59	0.018
	160	80	3.28	0.24	2.8	3.4	0.58	0.016
1954	0	0	3.33	0.40	3.6	2.2	0.52	0.038
	40	0	2.66	0.31	3.5	2.7	0.51	0.038
	80	0	2.74	0.25	3.9	2.2	0.45	0.032
	160	0	3.12	0.25	4.2	2.0	0.45	0 030
	320	0	3.63	0.22	4.2	2.0	0.45	0.032
1955	0	0	3.42	0.30	2.4	2.5	0.45	0.099
	40	0	2.90	0.24	2.3	2.7	0.45	0.104
	80	0	2.81	0.22	2.2	2.4	0.43	0.106
	160	0	3.50	0.23	2.3	2.3	0.43	0.087
	320	0	3.93	0.23	2.3	2.1	0.41	0.086

In every season, except 1953 when cyanamid supplied 170 pounds of nitrogen per acre, the nitrogen treatments were reflected in the growth and appearance of the plants. The low nitrogen and no nitrogen plots had plants which were stunted and chlorotic, signs typical of nitrogen deficiency. The higher rates of application of nitrogen produced plants with a deep green color and a vigorous vine. In some seasons the highest rates of application of nitrogen produced a vine so leafy that adequate spray coverage was difficult to obtain and near the ground the foliage and fruit remained moist most of the time. This condition increased the proportion of the fruit which was diseased. The 170 pounds of nitrogen from the broadcast application of cyanamid in the 1952 season completely masked the effect of the nitrogen fertilizer treatments. In 1953, when the plots received 80 pounds of nitrogen from cyanamid, only the check showed visible symptoms of nitrogen deficiency.

The yields followed the same pattern as the growth of the plants. The yields in pounds per 0.01 acre plot are shown in Tables 2 and 3. In each case value reported is the average of all of the replicates of the treatment. The average, for five years when no cyanamid was used, is shown in the last column. The yields of marketable fruit are reported to provide a comparison with commercial production. The yields of fruit of all grades are reported because most of the defects were caused by conditions not affected by fertilizer treatment.

The maximum yields of both marketable and total fruit was obtained with 160 or more pounds of nitrogen per acre every year except 1950. When cyanamid was used, the nitrogen it contained effectively replaced the nitrogen in the fertilizer. In the later years when no tankage was used the maximum yield response was still obtained at the same level of nitrogen fertilization, indicating that cyanamid, sulfate of ammonia, ammonium nitrate, urea and tankage were all equally effective under the conditions of the experiment. This is different from the results of Skinner and Ruprecht(5) who found that natural organics were markedly superior to the inorganic sources of nitrogen. In 1950 those plots which received 160 pounds of nitrogen per acre produced significantly less than those which received 80 pounds of nitrogen. Disease, particularly fusarium wilt, was extremely severe in the plots that season and the results cannot be considered typical. Furthermore in later years there was no significant depression in yield with the even higher applications of 320 and 330 pounds of nitrogen per acre. There was no significant depression in yield with these very high rates of application of nitrogen, but maximum yields were produced with 160 pounds of nitrogen.

Although the yields varied from year to year, there is no suggestion in the data that the check or low nitrogen plots were becoming progressively poorer or that the highest rates of application of nitrogen were gradually damaging the soil.

The yields in this experiment compare favorably with those in the area. There are, however, no published average yields comparable to those obtained in the experiment.

Figure 1, based on data presented in Table 4, shows the relationship between the nitrogen contents of the tomato leaves and the nitrogen applied to the plots in each of four years. The leaves from plots receiving 40 and 80 pounds of nitrogen per acre contained less nitrogen than those

leaves from plots which received no nitrogen at all. The curves above 100 pounds of nitrogen per acre are nearly parallel indicating that when the basic nitrogen requirements of the plant were met the nitrogen content of the tomato leaves increased approximately the same amount where the same quantity of nitrogen was applied to the soil. The increasing slope of the curves above 100 pounds of nitrogen per acre is evidence that the nitrogen content of the leaves was approaching a maximum for the conditions which prevailed during that season.

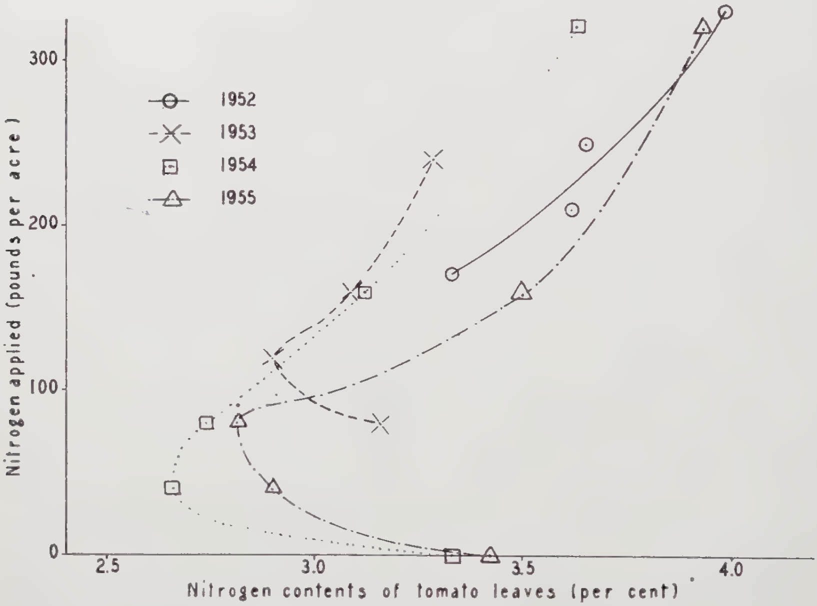

Figure 1. Total Nitrogen Content of Tomato Leaves Compared to Nitrogen Applied to the Soil in Four Crop Seasons.

That the nitrogen content of the tomato leaves at the end of the season should first be reduced and then increased as the amount of nitrogen applied to the soil increased can be explained on the basis of the growth of the plants. The plants on the check plots were so stunted in their early growth that they were unable to resume normal growth when the soil dried out and nitrogen became available at the end of the season. Where small applications of nitrogen stimulated the growth of the plants, the plants outgrew their limited supply and also that which became available at the end of the season. Where the nitrogen supply exceeded the growth and yield potential of the plants, nitrogen accumulated in the tissue as the supply increased. The yield data are consistent with this explanation of the difference in the nitrogen contents of the leaves.

To show the relationship between the nitrogen content of the leaves of the plants and the yields of marketable tomatoes in each of the four years, Figure 2 is presented. The coordinates show yield and nitrogen content and the curves were constructed by drawing a line through the

successive points corresponding to increasing rates of application of nitrogen. In 1952 when the fertilizer treatments were superimposed on a broadcast application of 170 pounds of nitrogen per acre from the cyanamid used for sclerotiniose control, there was an increase in the nitrogen content of the leaves with increasing rates of application of nitrogen but no increase in yield. In the last three seasons, 1953-1955, a horseshoe type curve was obtained. The leaves from the low nitrogen plots contained more nitrogen than the leaves from any of the plots except those which received nitrogen at the highest rates of application. The yields from the low nitrogen plants, on the other hand, give clear evidence of a deficiency of nitrogen during the major portion of the season. The nitrogen content of the leaves fell off as the increasing amount of fruit and the larger plants placed greater demand on the available nitrogen. The nitrogen content of the leaves increased again when the yields approached the maximum. When the maximum yields were obtained each increment of nitrogen applied to the soil increased the nitrogen content of the tomato leaves.

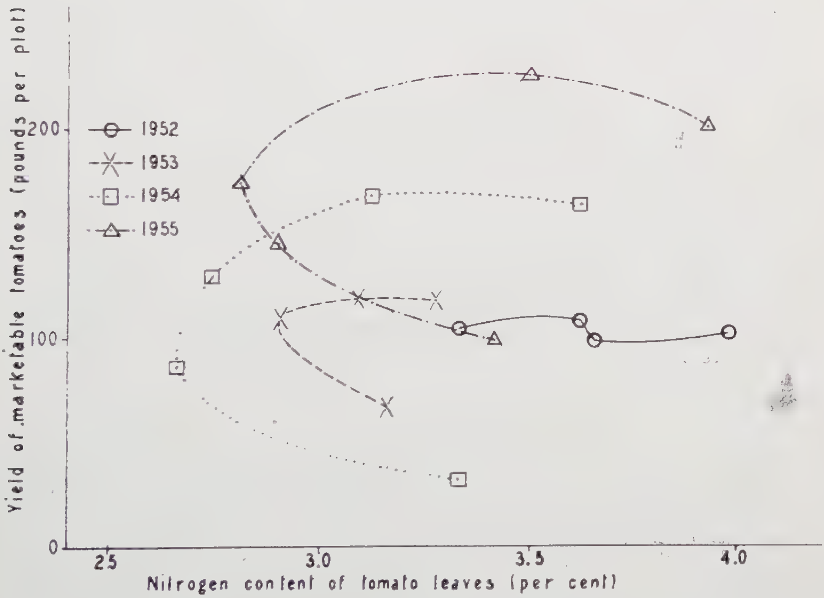

Figure 2. Total Nitrogen Content of Tomato Leaves Compared to Yields of Marketable Fruit in Four Crop Seasons. Constructed by drawing a smooth curve through successive points corresponding to increasing rates of application of nitrogen.

The phosphorus, potassium, calcium, magnesium, and manganese contents of the tomato leaves from the plots are also shown in Table 4. Within the limits of error of the experiment, there was no consistent relationship between these elements and nitrogen contents of the leaves or the nitrogen applied to the soil or the yields of fruit. Furthermore there was no consistent relationship between the contents of any of the other elements.

The marl in the Highlands area, where the tomato experiment was conducted, is deficient in available nitrogen. With all of the sources of nitrogen tested, including cyanamid which was broadcast before planting, the maximum yields were obtained with 160 or more pounds of nitrogen in addition to that supplied by the soil. Cyanamid, sulfate of ammonia, ammonium nitrate, urea and tankage were equally good sources of nitrogen. Until the nitrogen requirements of the plants were satisfied there was no build up of nitrogen in the leaves of the plants. Although high rates of application of nitrogen have been applied each year, there has been no intensification of the effects of the treatment with time. In the three years in which over 300 pounds of nitrogen per acre was applied, there was no significant reduction in yield at this high rate of application.

COMPARISON OF POTATO AND TOMATO EXPERIMENTS

The results of the potato and tomato experiments are in sharp contrast. While the potatoes gave no significant response to nitrogen fertilizer, the tomato yields increased as the rate of application of nitrogen increased up to 160 pounds of nitrogen per acre. While this is in part the result of a difference in the two species of plants, it is mostly the result of the difference in the amount of available nitrogen in the two soils. The well drained marl contains adequate available nitrogen for plant growth as shown by the yields and the nitrate nitrogen levels found during the crop season. In the poorly drained soils the nitrogen does not become available until the end of the dry season. The nitrogen content of the tomato leaves on the check plots is evidence that there is some release of nitrogen at the end of the season.

From the results of these experiments the use of nitrogen fertilizer on the very well drained marl, which has been farmed for a considerable number of years, is not justified for potatoes. In contrast nitrogen fertilizer at heavy rates of application is absolutely essential to the production of tomatoes on the deep, poorly drained marl.

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THE EFFECT OF AMMONIUM AND NITRATE NITROGEN ON THE EXCHANGE CAPACITY OF ROUGH LEMON ROOTS

I. W. Wander *

In an attempt to explain plant nutrition relationships, much work has been done recently in correlating the cation exchange capacity of different plant species with their ability to compete for plant nutrients. Although the cation exchange capacity of soils has long been recognized and evaluated, little practical significance was attached to the cation exchange capacity of plant roots until the work of Drake et al(1) was reported.

Plant physiologists have shown that actively sorbing portion of plant roots exhibit, at or near their surface, negative charges. A measurement of the number of these negatively charged spots per unit weight of roots is a measure of the cation exchange capacity of the roots. These negative charges attract positively charged nutrient ions such as ammonium, potassium, calcium and magnesium; hydrogen ions are released in the process. This exchange results in acidity and is a contributing factor to the subsoil acidity noted(7) in citrus areas located on the deep, poorly buffered sands of Central Florida.

Gray et al(2) indicated that plant roots of higher cation exchange capacity tend to sorb divalent cations such as calcium more readily than plant roots of lower cation exchange capacity. The same study also showed that plant roots of lower exchange capacity tend to sorb monovalent cations such as potassium more readily than calcium. Thus, the cation exchange capacity of the roots influences the amount and kind of cations sorbed. This, in turn, influences the nutrition of the plant.

Any condition which can alter the cation exchange capacity of a root system will therefore alter the nutrition of the entire plant. Although many investigators have assumed that the cation exchange capacity for a given plant species is relatively constant, evidence by McLean(4) indicates that it can be altered by the environment of the root system.

Nitrogen is one of the major elements utilized by plants and it can be supplied either as a monovalent cation (NH_4+) or anion ($NO_3—$) or both. For this reason, it is important to evaluate the effect of these two forms of nitrogen on roots. This becomes especially important on the poorly buffered, low exchange-capacity sandy soils of Central Florida where the form of nitrogen in the fertilizer application is readily transferred as such to the soil solution. An application of ammonium nitrogen on a low exchange-capacity sandy soil can result in a soil solution high in ammonium nitrogen; whereas the same application on a soil of higher exchange capacity would be sorbed and gradually released by nitrification to the soil solution as nitrate.

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* Soils Chemist, Citrus Experiment Station, Lake Alfred.

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It is, therefore, difficult under field conditions to determine whether trees are actually sorbing ammonium or nitrate nitrogen, even though a 100 percent ammonium nitrogen source is applied. To evaluate the effects of ammonium and nitrate nitrogen on citrus roots, and the resultant effects on nutrition as measured by leaf analysis, rough lemon seedlings were grown in nutrient solutions which furnished the same amount of nitrogen but differed in the form of nitrogen supplied. Rough lemon was used because it represents the major rootstock in Florida.

MATERIALS AND PROCEDURE

Rough lemon seedlings, previously grown in washed quartz sand, were selected for uniformity and placed in aerated, complete nutrient solutions that varied with respect to the form of nitrogen supplied. The seedlings were about four inches in height. There were eight treatments of four seedlings each. Two sets of seedlings received all their nitrogen from an ammonium source as $(NH_4)_2SO_4$, two as 50 percent ammonium and 50 percent nitrate nitrogen from NH_4NO_3, two as 25 percent ammonium and 75 percent nitrate nitrogen from a mixture of $(NH_4)_2SO_4$ and $NaNO_3$, and two as all nitrate nitrogen from $NaNO_3$. In one set of seedlings from each treatment, the pH of the nutrient solution was controlled by titrating with $Ca(OH)_2$ or H_2SO_4, as required, to a pH of 5.8 to 6.0 three times per week, using a glass electrode pH meter. The pH of the other set was not controlled. Treatments and nutrient composition are given in Table 1.

TABLE 1.—COMPOSITION OF NUTRIENT SOLUTIONS.

Treatment and Pot No.	Nitrogen Source, p.p.m.		Total Concentrations of Elements, p.p.m.*						
	NH_4N	NO_3N	N	P	K	Ca	Mg	S	Na
1 and 5	200	0	200	10	81	200	70	508	0
2 and 6	100	100	200	10	81	200	70	280	0
3 and 7	50	150	200	10	81	200	70	337	246
4 and 8	0	200	200	10	81	200	70	280	320

* The source of the nutrient salts were C. P. grades of $(NH_4)_2SO_4$, $NaNO_3$, KH_2PO_4, K_2SO_4, $MgSO_4 \cdot 7H_2O$, and $CaSO_4 \cdot 2H_2O$. Minor elements were supplied as H_3BO_3, $MnSO_4 \cdot H_2O$, $ZnSO_4$, $7H_2O$, $CuSO_4$, $5H_2O$ and $H_2MoO_4 \cdot H_2O$ to furnish 0.5 p.p.m. B, 0.5 p p.m. Mn, 0.25 p.p.m. Zn, 0.1 p.p.m. Cu and 0.01 p.p.m. Mo. Iron was supplied as $FeC_4N_4O_6$ to furnish 2.0 p.p.m. Fe.

Records were kept of the change in pH of the nutrient solution and of the amount of base $Ca(OH)_2$ or acid (H_2SO_4) required to adjust the pH in the treatments that were controlled. Frequent samples of the nutrient solution were taken to follow changes in the ammonium and nitrate concentrations. This was done to determine if nitrification of ammonium sources was occurring and as a basis of changing nutrient solutions when the nitrogen was depleted.

The seedlings were grown in a greenhouse for a total of 160 days, during which the nutrient solutions were completely replaced five times. At the end of the 160 day period, the seedlings were photographed and the leaves and roots harvested for analysis. Total dry weight of the leaves produced in each treatment was recorded. Total nitrogen in the leaves was determined by the Kjeldahl procedure and total leaf calcium, potassium, and magnesium were estimated by digesting the dried ground leaves with nitric and perchloric acids, then using a diluted aliquot for flame analysis. The exchange capacity of the roots was estimated by the method outlined by Drake et al (2).

RESULTS AND DISCUSSION

The appearance of the tops and roots of the seedlings grown in the different nitrogen sources without pH control is shown in Figure 1. The total dry weight of leaves produced by the four seedlings in each treatment varied from 6.5 grams where all ammonium nitrogen was supplied to 25.0 grams where all nitrate nitrogen was supplied. The dry weight of leaves produced in all treatments is given Table 2.

Figure 1. Appearance of tops and roots of rough lemon seedlings grown in nutrient solutions for 160 days with ammonium or nitrate nitrogen or combinations of both without pH control. No. 1—$(NH_4)_2SO_4$; No. 2—NH_4NO_3; No. 3—25 percent $(NH_4)_2SO_4$, 75 per cent $NaNO_3$; No. 4—$NaNO_3$. See Table 1 for complete nutrient composition. Numerals on left represent inches.

In the 100 percent ammonium source without pH control, the nutrient solution would drop as low as pH 2.6 and stay below pH 3.5. With the ammonium nitrate source, the solution pH would drop to 3.0 and vary between 3.0 and 4.0. The mixture of 25 percent ammonium and

TABLE 2.—AMOUNT OF $Ca(OH)_2$ OR H_2SO_4 REQUIRED FOR pH CONTROL, DRY WEIGHT OF LEAVES PRODUCED, LEAF COMPOSITION AND EXCHANGE CAPACITY OF ROOTS FROM ROUGH LEMON SEEDLINGS FURNISHED VARYING NITROGEN SOURCES WITH AND WITHOUT pH CONTROL FOR A PERIOD OF 160 DAYS.

Treatment No.	Nitrogen Source	Milliliters $Ca(OH)_2$ 0.1 N or H_2SO_4 0.1 N	Dry Weight Leaves Produced (Grams)	Per Cent, Dry Weight Basis in Leaves				Exchange Capacity of Roots M.E./100 g D.W.B.*
				N	Ca	K	Mg	
	pH Not Controlled							
1	100% NH_4		6.5	4.85	0.91	0.91	0.11	....
2	50% NH_4 50% NO_3		12.1	3.20	1.25	1.21	0.23	10.0
3	25% NH_4 75% NO_3		21.0	2.25	1.78	1.40	0.26	22.0
4	100% NO_3		25.0	2.15	2.80	1.32	0.21	37.0
	pH Controlled							
5	100% NH_4	777**	15.5	2.72	1.68	1.08	0.19	12.0
6	50% NH_4 50% NO_3	443**	24.7	2.14	2.60	1.25	0.28	15 0
7	25% NH_4 75% NO_3	302**	24.9	2.13	2.15	1.28	0.19	25.0
8	100% NO_3	77***	26.5	2.05	2.90	1.15	0.18	36.0

* D.W.B.—Dry weight basis.
** $Ca(OH)_2$.
*** H_2SO_4.

75 percent nitrate nitrogen would initially drop to pH 3.2, then gradually rise to as high as 6.6, then again drop to below 4.0. The 100 percent nitrate nitrogen solution would sometimes show an initial slight drop below 5.8, then would rapidly rise to pH 7.8 to 8.0. After maintaining a high pH for several days, the solution would become acid and drop as low as pH 3.5. The change from a high to a low pH coincided with the depletion of nitrate nitrogen in the nutrient solution. There appeared to be a direct relationship between active acidity developed and the amount of ammonium nitrogen supplied in the nutrient solution. There also appeared to be some acidity resulting from the greater sorption of cations over anions in the 100 percent nitrate nitrogen source after the nitrate had been completely utilized. At no time did any nitrate appear in the all ammonium nitrogen source solutions, thus indicating that the solutions were free of the effects of nitrification.

Figure 2. Appearance of tops and roots of rough lemon seedlings grown in nutrient solutions for 160 days with ammonium or nitrate nitrogen or combinations of both with pH control. No. 5—$(NH_4)_2SO_4$; No. 6—NH_4NO_3; No. 7—25 percent $(NH_4)_2SO_4$, 75 percent $NaNO_3$; No. 8—$NaNO_3$. See Table 1 for complete nutrient composition. Numerals on left represent inches.

The appearance of the seedlings growing in the pH-controlled nutrient solutions is shown in Figure 2. A record of the amount of $Ca(OH)_2$, calculated on the basis of 0.1 N, or 0.1 N H_2SO_4 required to bring the nutrient solution to pH 5.8 three times per week, is given in Table 2. It is evident that the higher percentages of ammonium nitrogen supplied by the nutrient solutions and taken up by the roots, required correspondingly greater amounts of basic material for pH control. It was also noted that a rapid change in pH occurred shortly after titration. The

pH of the nutrient solutions containing $(NH_4)_2SO_4$ and NH_4NO_3 would drop nearly two units within two hours after titration. It is evident that close control of hydrogen-ion concentrations in poorly buffered nutrient solutions containing ammonium nitrogen and in the presence of actively sorbing plant roots is difficult.

The appearance of the type of roots produced, as shown in Figures 1 and 2, indicates that either the ammonium nitrogen source or the inability to constantly control the acidity of the solutions resulted in a distinctly inferior root system. The feeder roots produced in the all ammonium nitrogen solutions — even with pH control — were short, thickened, dark brown in color and few in number. As the proportion of nitrate nitrogen increased, the feeder roots became more numerous, longer, thinner and whiter in color. The observation that the short thickened roots were inferior was substantiated by measuring the cation exchange capacity of the roots from the different treatments.

When all ammonium nitrogen was the nitrogen source furnished and the pH was not controlled, insufficient roots were produced to make a measurement. The exchange capacity of the rough lemon roots grown under the conditions described varied from 10 to 37 milliequivalents per 100 grams dry weight of roots (Table 2). The value of 37 milliequivalents per 100 grams dry weight of roots found in the nitrate nitrogen treatments agrees with the value found for roots from mature trees in good condition in commercial groves in Florida that are budded on rough lemon. Smith and Wallace(5) give a value of 30 m.e. per 100 grams dry weight for rough lemon and 20 m.e. for grapefruit roots. They state that grapefruit roots consistently had the lowest cation exchange capacity of the rootstocks studied. Thus, the value of 10 m.e. per 100 grams dry weight of roots is much lower than would be expected for rough lemon roots.

This effect on the cation exchange capacity of rough lemon roots was due either to the direct sorption of ammonium ions or to the resultant increase in active acidity which was difficult to control constantly. Thus, rough lemon roots were produced which were even lower in cation sorptive capacity than grapefruit roots which are recognized as being poor. This being the case, then, an unbalanced cation nutrition could occur in the field where a large proportion of the nitrogen is being supplied as ammonium nitrogen unless nitrification of the applied ammonia is rapid.

Analysis of the leaves (Table 2) reflected the influence of the changes noted in the roots. Total leaf nitrogen indicated a direct relationship between the amount of ammonium nitrogen supplied in the nutrient solution and total nitrogen in the leaves. This relationship was more pronounced when the pH of the nutrient solution was not controlled. A similar relationship was noted in citrus by van der Merwe(6) and in tobacco by McEvoy(3). Even though the percent leaf nitrogen was higher in the seedlings supplied with ammonium nitrogen, the total amount of nitrogen utilized by the seedlings furnished nitrate was much higher when based on the greater dry weight of leaves produced.

Analysis for leaf calcium revealed an inverse relationship to ammonium supplied, the higher the ammonium nitrogen nutrition, the lower the leaf calcium. A lower leaf calcium was found even in the pH controlled series where more calcium, as $Ca(OH)_2$, was supplied to the

ammonium cultures than was provided in the nitrate treatments. A similar repression of the calcium in the leaves of citrus was noted by van der Merwe(6) and in tobacco by McEvoy(3) when nitrogen was supplied in the ammonium form.

No definite relationship between leaf potassium on a percentage basis and nitrogen source (Table 2) was established, but when the total weight of leaves produced was considered, only about one-sixth as much potassium was utilized from the non-pH controlled ammonium nitrogen treatment compared to the nitrate treatment. A similar but less pronounced trend was noted in the pH controlled series. The total amount of magnesium utilized by the seedlings, as measured by leaf composition and total dry weight of leaves produced, was less in the all ammonium nitrogen source treatment than in the all nitrate treatment. The trend was similar but less pronounced to that found for calcium.

CONCLUSION

Observations made from a nutrient culture experiment using rough lemon seedlings indicate that ammonium nitrogen sorption or the resultant active acidity produced can alter the cation sorbing capacity of the root system. This results in a decreased sorption of other cations, especially calcium. This would indicate that field practices, such as close pH control of the soil, should be followed to favor rapid nitrification of applied ammonium sources. Where nitrification is poor, nitrate nitrogen sources should be used until good nitrifying conditions can be established.

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PRELIMINARY REPORT ON THE EFFECT OF NITROGEN SOURCE AND RATE AND LIME LEVEL ON pH, ROOT GROWTH, AND SOIL CONSTITUENTS IN A MARSH GRAPEFRUIT GROVE

Paul F. Smith* and Walter Reuther**

Since the advent of copper toxicity as a soil factor in citrus production, greater interest has developed in soil acidity, as this largely affects the degree of copper damage. Nitrogen source has consequently become of considerable interest because certain forms of nitrogen are known to be acidifying. Little information exists as to the most desirable form of nitrogen for citrus or the effect of lime level. For these reasons an experiment was started in a 10-year-old Marsh seedless grapefruit grove on Rough lemon stock on Lakeland fine sand near Groveland in the spring of 1953, in an attempt to broaden our knowledge on the relation of nitrogen source and soil acidity to tree behavior. The results are presented as a progress report to provide current information on this important topic.

EXPERIMENTAL PROCEDURE

Three sources of nitrogen are included as representative of extremes in acidulation properties. These are calcium nitrate, ammonium nitrate, and ammonium sulfate. Nitrogen from each source is applied at two rates: 1.75 and 3.5 lbs. of N per tree per year. One-half of the plots have been limed rather heavily with dolomitic limestone (5 tons per acre so far) to maintain the top 6 inches at a pH above 6.0 at all times. The other half have received no lime for the past 3 years but will be limed with dolomite as necessary to keep the pH of the topsoil above 5.0. In factorial combination these make 12 treatments ($3 \times 2 \times 2 = 12$). Each treatment is applied by machine to a double-rowed, 6-tree plot. Each treatment is repeated 3 times making 36 six-tree plots in the experiment. Guard rows surround the individual plots. The treatments are applied in 2 equal applications in March and October. Sufficient high calcium limestone is applied once yearly to the low pH plots to equalize the Ca supply. Thus, the low pH ammonium nitrate and ammonium sulfate plots receive the same amount of Ca as the calcium nitrate plots but in the form of $CaCO_3$.

In addition to these differential treatments, all trees receive 2.0 lbs. of K_2O per year from two equal applications of sulfate of potash magnesia at the times mentioned above. Borax and lead arsenate are applied yearly as sprays by the owner, and each tree receives about 4 lbs. of

* Plant physiologist, U. S. Dept. of Agr., Horticultural Field Station.

** Horticulturist (resigned) U. S. Department of Agriculture, Horticultural Field Station, Orlando, ** now Head, Dept. Horticulture, College of Agriculture, Gainesville.

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sulfur yearly for mite control. There are 58 trees to the acre. Copper and manganese had been consistently used in the fertilizers during the first 10 years of the life of the grove and further application of these elements was not deemed necessary.

Growth, yield, fruit quality, and mineral status of the foliage are being carefully followed, but the results are not presented in detail here, as differences are not appreciable so far.

In June 1955, 2½ years after the start of the experiment, the soil of each plot was sampled to a depth of 5 feet by taking 8 cores at the tree drip with a 2-inch soil tube. The 8 cores were composited by empirical depths, screened, and mixed by rolling back and forth on a canvas. The arbitrary depths chosen were 0-6, 6-12, 12-24, 24-42, and 42-60 inches. The fibrous roots for each depth were saved and the dry weights determined. Tightly adhering soil particles may constitute 10 to 20 percent of the "root weight" as determined, but are probably independent of treatment.

Sub-samples of the 180 soil samples were screened through a 20-mesh screen and extracted with Morgan's solution (sodium acetate, pH 4.8) and the filtrate clarified with activated carbon. NH_4, NO_3, K, Mg, and Ca were determined. The Ca values seemed unduly high and irregular, apparently because of digestion of residual lime and interference of sodium in flame analysis. Therefore, additional sub-samples were extracted with ammonium acetate (pH 7.0), which gave lower but more consistent values for Ca, and these values are presented in the tables. The methods of Peech and English(4) were used for determining NH_4, NO_3, and Mg except that a colorimeter was used instead of visual comparisons. Determinations of K and Ca were made on a Beckman Du flame photometer. Determinations of pH were made on a 1:1 mixture of soil and water with a glass electrode meter.

RESULTS AND DISCUSSION

Soil pH. For brevity, only grand means of the pH measurements are presented in Table 1. This masks the extreme values of individual treatments but all salient points are illustrated since there were no interactions. The effects of nitrogen source on pH were greatest at the 6-12 inch depth, and all the acidulating effect of the ammoniacal sources was limited to the top 24 inches. This suggests that nitrification takes place primarily in the top foot of soil, and probably in the top 6 inches, as that zone is much more highly buffered than lower depth, and also it received the supplementary calcium carbonate. As is well known, ammonium sulfate was more acidifying than ammonium nitrate.

The ammonium nitrate plots tended to run slightly lower in pH than the calcium nitrate plots in the top 24 inches and slightly higher in the lower 36 inches; this was true regardless of lime level and the fact that equal calcium was supplied to the low-lime plots. Theoretically, the supplementary calcium carbonate should make the acid input of these plots equal. The ammonium sulfate plots were considerably lower in pH in the upper 24 inches but almost identical to the calcium nitrate plots in the lower 36 inches. In this case the supplementary calcium carbonate would be theoretically equivalent to about half of the acid input of ammonium sulfate.

TABLE 1.—MEAN SOIL pH AT VARIOUS DEPTHS IN A MARSH GRAPEFRUIT GROVE AS RELATED TO NITROGEN SOURCE, NITROGEN RATE, AND DOLOMITIC LIME RATE.

Treatments	0 6 Inches	6-12 Inches	12-24 Inches	24-42 Inches	42-60 Inches
Source					
$Ca(NO_3)_2$	5.99	5.18	4.88	4.72	4.75
NH_4NO_3	5.90	5.01	4.79	4.80	4.92
$(NH_4)_2SO_4$	5.71	4.79	4.64	4.67	4.74
F-Value	*	***	***	N.S.	*
R_2-Value	0.18	0.11	0.10	......	0.15
R_3-Value	0.19	0.12	0.11	......	0.16
N Rate					
1.75#/tree	5.90	5.09	4.82	4.80	4.83
3.50#/tree	5.83	4 90	4.72	4.67	4.70
F-Value	N.S.	***	*	*	*
R_2-Value	......	0.09	0.08	0.11	0.12
Dolomite Rate					
None	5.26	4.81	4.67	4.61	4.65
5 tons/acre	6.48	5.18	4.88	4.85	4.95
F-Value	***	***	***	***	***
R_2-Value	0.14	0.09	0.08	0.11	0.12

* Indicates statistical significance at odds of 19:1.
** Indicates statistical significance at odds of 99:1.
*** Indicates statistical significance at odds of 999:1.
N.S.—Difference found is not significant at odds of 19:1.
R_3—Shortest significant range between largest and smallest of three means at odds of 19:1 as proposed by Duncan(1).
R_2—Is the usual L S.D. and is the shortest range necessary for significance in all other mean comparisons at odds of 19:1.

The high rate of nitrogen gave lower mean pH values at all depths. The main effect was in the 6-12 inch zone and even calcium nitrate showed a reduction in this zone. At all other depths there was little or no difference between the two rates of calcium nitrate, and the slight overall mean differences are due principally to the high level of ammonium sulfate. The acidulating effect of the calcium nitrate in the 6-12 inch zone seemed anomolous at first as this salt should be neutral to slightly alkaline in reaction. Laboratory tests showed, however, that the pH increased when the samples were rinsed with distilled water, as though free acid was being removed. This increase in pH reading was more marked with calcium nitrate than with the ammoniacal sources. This observation is also supported by the fact that the extractable calcium was appreciably less in the 6-12 inch zone in the ammoniacal nitrogen plots (Table 6). Thus it must be realized that pH readings as taken are highly empirical, and the fact that all three nitrogen sources gave lowered readings in the 6-12 inch zone may be only coincidental. Calcium nitrate apparently caused

TABLE 2.—MEAN DRY WEIGHT (GMS.) OF FIBROUS ROOTS IN EIGHT 2-INCH CORES AT VARIOUS DEPTHS IN A MARSH GRAPEFRUIT GROVE IN RELATION TO NITROGEN SOURCE, NITROGEN RATE, AND LIME RATE.

Treatments	0-6 Inches	6-12 Inches	12-24 Inches	24-42 Inches	42-60 Inches
Source					
$Ca(NO_3)_2$	1.14	0.74	1.52	2.26	1.10
NH_4NO_3	1.13	0.89	1.64	2.30	1.06
$(NH_4)_2SO_4$	1.14	0.79	1.55	2.07	0.92
F-Value	N.S.	N.S.	N.S.	N.S.	N.S.
N Rate					
1.75#/tree	1.16	0.83	1.80	1.96	1.10
3.50#/tree	1.11	0.78	1.34	2.46	0.95
F-Value	N.S.	N.S.	**	*	N.S.
R_2-Value	......	......	0.29	0.43	......
Dolomite Rate					
None	1.24	0.80	1.61	2.15	0.95
5 tons/acre	1.02	0.81	1.53	2.27	1.10
F-Value	N.S.	N.S.	N.S.	N.S.	N.S.

See Table 1 for explanation of statistical symbols.

TABLE 3.—P.P.M. SOIL N (ALL NITRATE) AT VARIOUS DEPTHS IN RELATION TO NITROGEN SOURCE, NITROGEN RATE, AND LIME RATE.

Treatments	0-6 Inches	6-12 Inches	12-24 Inches	24-42 Inches	42-60 Inches
Source					
$Ca(NO_3)_2$	6.5	5.1	2.5	3.4	3.4
NH_4NO_3	5.6	5.3	3.2	4.0	2.8
$(NH_4)_2SO_4$	6.3	5.0	3.7	3.7	3.6
F-Value	N.S.	N.S.	*	N.S.	N.S.
R_2-Value	.....	..	0.8		......
N Rate					
1.75#/tree	5.8	4.8	2.6	3.0	2.4
3.50#/tree	6.4	5.5	3.7	4.4	4.2
F-Value	N.S.	N.S.	**	***	***
R_2-Value	......	......	0.7	0.6	0.8
Dolomite Rate					
None	6.0	5.0	2.8	3.6	3.0
5 tons/acre	6.2	5.2	3.5	3.8	3.6
F-Value	N.S.	N.S.	*	N.S.	N.S.
R_2-Value	......	......	0.7	......	......

See Table 1 for explanation of statistical symbols.

the downward movement of displaced hydrogen while nitrification processes with ammoniacal nitrogen led to base removal; both of these processes would depress pH. Leaching, thus, must be taken into consideration in determining the true pH of lightly buffered soils. It is apparent that in Florida citrus groves soil samples for pH determination should be taken at the end of the rainy season, instead of at the beginning as in the present test, and as long after the last fertilization as practical.

The rate of liming affected pH readings at all depths. The main effect, however, was in the top 6 inches. This result, plus the fact that the calcium content of the subsoil was not increased by liming as shown in Table 6, attests to the immobility of lime and suggests that the small increases in subsoil pH actually result from reduction in acid input rather than acid neutralization at the lower depths.

Feeder Root Development. From the overall standpoint there was no effect of treatment on total functional feeder roots of Marsh grapefruit in the top 5 feet of soil (Tables 2 and 7). The greatest concentration of roots was in the 0-6 inch zone and the total weight of roots in the 5 feet was about double that found by Ford(2) for trees of this age on Rough lemon stock. The only significant effect of treatment was a shift in root density in the 12-24 and 24-42 inch depths at the high nitrogen level. The absence of treatment interactions indicates that the three nitrogen sources had similar effects. The results appear to be noteworthy since these small roots doubtlessly developed during the experimental period.

TABLE 4.—P.p.m. K in Soil at Various Depths in Relation to Nitrogen Source, Nitrogen Rate, and Lime Rate.

Treatments	0-6 Inches	6-12 Inches	12-24 Inches	24-42 Inches	42-60 Inches
Source					
$Ca(NO_3)_2$	14.0	7.3	6.4	5.7	5.7
NH_4NO_3	16.5	8.3	6.0	5.6	5.6
$(NH_4)_2SO_4$	13.7	7.2	7.0	6.2	5.6
F-Value	N.S.	N.S.	N.S.	N.S.	N.S.
N Rate					
1.75#/tree	15.0	8.3	7.0	6.2	5.6
3.50#/tree	14.4	7.0	5.9	5 4	5.6
F-Value	N.S.	N.S.	N.S.	N.S.	N.S.
Dolomite Rate					
None	13.0	6.9	6.1	5.7	5.5
5 tons/acre	16.4	8.4	6.8	5.9	5.7
F-Value	*	*	N.S.	N.S.	N.S.
R_2-Value	3.1	1.5	......	......	......

See Table 1 for explanation of statistical symbols.

NITROGEN CONTENT OF SOIL. Ammoniacal nitrogen was found only in trace amounts (usually less than 0.1 p.p.m. N) regardless of treatment, indicating that satisfactory nitrification was taking place at both lime levels. No data are presented for this factor. Nitrate nitrogen was found readily in all plots and at all depths (Table 3). The main thing that influenced the presence of NO_3 was the rate of nitrogen supply (Tables 3 and 7). The high rate of nitrogen supply caused notable increases at the lower soil depths. The high rate of dolomitic lime appeared to favor the retention of NO_3 slightly at all depths, but the difference was statistically significant only in the 12-24 inch samples and the total amount for the 5-foot layer of soil. Again no interaction was evident, indicating that nitrogen source was not a major factor in the nitrogen status of the soil 90 days after the spring fertilization.

TABLE 5.—P.P.M. MG IN SOIL AT VARIOUS DEPTHS IN RELATION TO NITROGEN SOURCE, NITROGEN RATE, AND LIME RATE.

Treatments	0-6 Inches	6-12 Inches	12-24 Inches	24-42 Inches	42-60 Inches
Source					
$Ca(NO_3)_2$	146	8.2	5.0	2.9	6.2
NH_4NO_3	132	7.5	3.4	5.8	6.2
$(NH_4)_2SO_4$	122	6.7	3.7	8 2	5.2
F-Value	N.S.	N.S.	N.S.	**	N.S.
R_2-Value	......	......	......	3.2	......
R_3-Value	......	......	......	3.4	......
N Rate					
1.75#/tree	149	8.8	5.6	7.4	7.3
3.50#/tree	118	6.1	2.5	3.9	4.3
F-Value	*	*	*	*	*
R_2-Value	25	2.0	2.6	2.6	2.6
Dolomite Rate					
None	24	3.5	2.9	2.8	3.3
5 tons/acre	243	11.4	5.1	8.6	8.4
F-Value	***	***	N S.	***	***
R_2-Value	25	2.0	2.6	2.6	2.6

See Table 1 for explanation of statistical symbols.

POTASSIUM CONTENT OF SOIL. The potassium content showed no relation to nitrogen source (Table 4). The high rate of nitrogen appeared to favor slightly the loss of potassium from the top 5 feet (Table 7). The high rate of lime tended to retard potassium movement, particularly in the top 6 inches (Tables 4 and 7). Peech reported(3) that liming reduces the loss of potassium by leaching.

MAGNESIUM CONTENT OF SOIL. Nitrogen source had very little effect on the extractable magnesium (Tables 5 and 7). The data suggest that the baseless nitrogen sources have a tendency to move magnesium downward from the topsoil. This is indicated by the reverse trends found in the 0-6 and 24-42 inch depths. The high nitrogen rate, regardless of nitrogen source, reduced the magnesium concentration at all depths. The reduced magnesium for the total depth (Table 7) apparently represents leaching loss induced by high nitrogen. The lime rate vastly affected the magnesium extracted from the topsoil and the increase probably represents solubilization of the magnesium carbonate in dolomite by the acidic extracting solution. It is also apparent that the dolomite contributes magnesium to the subsoil.

TABLE 6.—P.P.M. CA IN SOIL AT VARIOUS DEPTHS IN RELATION TO NITROGEN SOURCE, NITROGEN RATE, AND LIME RATE.

Treatments	0-6 Inches	6-12 Inches	12-24 Inches	24-42 Inches	42-60 Inches
Source					
$Ca(NO_3)_2$	279	41.8	18.8	12.8	16.8
NH_4NO_3	269	32.2	19.7	20.7	16.8
$(NH_4)_2SO_4$	249	34.3	19.0	20.5	17.1
F-Value	*	*	N.S.	*	N.S.
R_2-Value	26	8 0	......	6.1	......
R_3-Value	27	8.4	......	6.4	......
N Rate					
1.75#/tree	269	38.8	20.1	21.1	18.6
3.50#/tree	263	33.4	18.2	14.8	15.2
F-Value	N.S.	N.S.	N.S.	*	N.S.
R_2-Value	......	......	......	5.0	......
Dolomite Rate					
None	185	34.2	18.0	17.4	16.4
5 tons/acre	346	38.0	20.3	18.6	17.4
F-Value	***	N.S.	N.S.	N.S.	N.S.
R_2-Value	22	......	......	......	......

See Table 1 for explanation of statistical symbols.

CALCIUM CONTENT OF SOIL. The calcium extracted by neutral ammonium acetate appears to be a conservative measure of this element. Sodium acetate extracts removed more calcium from samples of all depths, but the values were less consistent among replicates than the ammonium acetate values presented in Tables 6 and 7.

Nitrogen source had no effect on the extractable calcium in the 5-foot depth. As with magnesium, however, there was a tendency for the baseless nitrogen sources to displace calcium from the top foot of soil and

to increase the amount in the 24-42 inch depth. There was also a tendency for the high nitrogen rates to remove calcium throughout the depth sampled, but the overall effect was not of quite sufficient magnitude to be statistically significant.

The rate of lime application greatly increased calcium in the top 6 inches but had practically no effect on that in the lower depths.

TABLE 7.—TOTAL AMOUNTS OF ROOTS AND CHEMICAL CONSTITUENTS FOUND PER 5 FEET IN RELATION TO SOIL TREATMENTS.

Treatment	Feeder Roots*	Pounds per Acre			
		N	K	Mg	Ca
N Source					
$Ca(NO_3)_2$	38.7	74.6	137	358	894
NH_4NO_3	40.2	75.2	140	365	906
$(NH_4)_2SO_4$	37.1	81.0	139	353	868
F-Value	N.S.	N.S.	N.S.	N.S.	N.S.
N Rate					
1.75#/tree	38.1	64.2	146	426	934
3.50#/tree	38.0	89.7	133	307	846
F-Value	N.S.	***	*	**	N.S.
R_2-Value	-----	6.6	10.2	72	-----
Dolomite Rate					
None	38.7	72.7	131	103	714
5 tons/acre	37.4	81.1	147	631	1066
F-Value	N.S.	*	**	***	***
R_2-Value	-----	6.6	10.2	72	102

* Total dry weight of feeder roots calculated per sq. ft. column 5 ft. deep. See Table 1 for explanation of statistical symbols.

GENERAL DISCUSSION

In considering the results it is pertinent to remember that approximately 250 pounds of sulfur is applied annually to these trees, which is a major factor in the acid input in all treatments. Sulfofication would thus require the equivalent of about 300 pounds of calcium per acre annually, which is equal to the calcium carried by the high rate of calcium nitrate. Thus, conceivably the unlimed high calcium nitrate plots might be practically holding their own so far as soil acidity is concerned. However, the plots treated with calcium nitrate at the two rates did not show appreciable differences in pH or extractable calcium values, and both have become slightly more acidic since the start of the experiment (0-6 in., 5.6 in 1953; 5.3 in 1955). This suggests that a substantial portion of the applied calcium nitrate has leached out as the intact salt. Crop removal accounts for about 40 percent of the nitrogen applied at the low

rate and 20 percent at the high. Leaching of nitrogen from the ammoniacal sources was of the same magnitude, but such a movement would be acidifying in the zone where nitrification took place.

The relatively slight effect of the high rate of liming on subsoil pH substantiates previous studies such as those of Volk and Bell(5) and Wander(6). There is, however, no evidence here to support the postulation of Wander(6) that a substantial part of subsoil acidity in light Florida soils is attributable to the leaching of ammonia to the subsoil where nitrification stops but where direct ammonia absorption produces acidity. Amomnia was not found in appreciable amounts in any extracts indicating that either it didn't move into the subsoil or else it was nitrified there. Absorption of base elements from the subsoil would result in acidity development, and this may be an important factor in the acidulation of the subsoil under cultivation.

The differences in acidity due to nitrogen source were not found to be great. Whether these differences will increase with time remains to be seen. Subsoil acidity needs further study in relation to citrus root growth. The present results indicate that good root development may occur when the pH is in the range of 4.6 to 4.8, at which level the exchange complex is largely saturated with hydrogen-ion. If yield, tree growth, and fruit quality remain relatively unaffected, as they have during the first 3 years of this test, the source of nitrogen cannot be considered as a primary factor in citrus production on Florida acid sandy soils.

SUMMARY

Analysis of soil samples to a depth 5 feet in a factorial nitrogen-source, nitrogen-rate, and lime-rate experiment with Marsh grapefruit on Lakeland fine sand indicates that after 2½ years of treatment (1) ammoniacal-nitrogen carriers lowered the pH primarily in the 6-12 inch depth, (2) ammonium sulfate is considerably more acidifying than ammonium nitrate when compared with calcium nitrate, (3) root growth was unaffected by treatment, (4) increased rates of nitrogen gave slightly lower pH values although calcium nitrate was practically negligible in this regard, (5) high dolomitic lime applications greatly raised the pH of the top 6 inches and slightly raised subsoil pH readings, and (6) the high rate of liming gave a higher magnesium, potassium, and nitrate nitrogen content in the top 5 feet of soil but increased calcium appreciably only in the top 6 inches.

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MOBILITY OF UREA NITROGEN APPLIED TO FLORIDA SOILS

G. M. Volk and A. W. Sweat*

Urea is now used as a fertilizer material to an extent that justifies intensive investigation of its value as a source of nitrogen. It differs markedly in some respects from other nitrogen carriers, yet has much in common with anhydrous ammonia.

Urea is readily converted to ammonia in average soils by biological processes or by the urease enzyme resulting from them. Prior to this conversion it moves quite readily with the soil water, especially at high concentrations(4). There is also a certain amount of diffusion movement of the type that takes place without actual movement of water.

The ammoniacal nitrogen resulting from conversion of urea is strongly alkaline, similar to anhydrous ammonia. The alkaline form of ammoniacal nitrogen differs from that of neutral salts such as ammonium sulfate and ammonium nitrate: it will readily replace or unite with hydrogen of the base exchange complex and thus become relatively resistant to leaching. On the other hand, neutral forms of ammonia are not efficient in replacing hydrogen and, therefore, are quite mobile in strongly acid sandy soils(3).

Alkaline ammonia also may become fixed to some extent in difficultly available form by certain mineral colloids in the soil in a manner similar to that of potassium(1). The possibility also exists for fixation of urea or ammonia by direct chemical or physical reaction with organic soil constituents.

The relative mobility of urea nitrogen under different conditions is particularly important in determining the efficiency of its utilization by plants and its effect on the acidity of the soil profile(5). Thus, the fixation of urea as such by soils, the extent of its period of mobility as urea, and the relative resistance of the alkaline form of ammonia to movement in the soil are of primary concern in any comparison of urea to other carriers of fertilizer nitrogen. It is the purpose of this report to present the results of a survey of various soil factors involved in the mobility of urea nitrogen in Florida soils in an attempt to determine which might justify further investigations.

The mobility and efficiency of urea as compared to ammonium nitrate was first examined by using heavy rates of nitrogen on lysimeters 22 square feet in area and 4 feet deep, filled with Lakeland fine sand and planted to pasture grasses. A previous report of this study(6) indicated that urea was less acidifying to the soil than was ammonium nitrate, but that crop utilization and leaching losses were similar. The soil pH dropped from pH 6.34 to pH 5.43 in the surface two inches where a total of 840 pounds of urea nitrogen had been used at a rate of 60 pounds

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* Soils Chemist and Laboratory Assistant, respectively, Agr. Expt. Station, Gainesville.

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per month for two growing seasons. This compares to a drop from pH 6.24 to pH 4.92 where an equal amount of ammonium-nitrate nitrogen was used. The pH of the 2 to 10 inch depth dropped from 6.34 to 5.64 with urea, and from 6.24 to 5.43 with ammonium nitrate. In the 10 to 18 inch depth the pH was raised from 5.52 to 6.01 with urea, and from 5.48 to 5.77 with ammonium nitrate.

It appeared that the urea largely converted to ammonia and nitrate in the surface soil and was used there to a greater extent than was the ammonium nitrate. The potential for movement of the latter into the subsoil was much greater because of the relatively greater mobility of the neutral salt. The pH differential indicated either a greater utilization of bases from the surface soil in the presence of ammonium nitrate or greater movement of bases into the subsoil below the 18 inch depth, or a combination of both.

At the conclusion of the above study, the lysimeters were used to determine the relative losses of nitrogen from applications of urea, ammonium nitrate, and ammonium sulfate, if leaching took place immediately after application of the materials. Data appear in Table 1. Leaching with approximately 1/8 inch increments of water at five minute intervals for five hours produced a total of five inches of leachate in 24 hours and removed approximately 33 percent of the applied nitrate nitrogen, 15 percent of the urea nitrogen as urea, but no measurable ammonia nitrogen.

TABLE 1.—Leaching of Urea Nitrogen through a Four-Foot Profile of Lakeland Fine Sand by Five Inches of Water Passing in 24 Hours.

Lbs. N/A and Source	Lysimeter No.	Urea-N Leached		Nitrate-N Leached	
		Lbs./A.	Percent Leached	Lbs./A.	Percent Leached
60 lbs. N Urea	1	9.8	16%	.15	
	6	10 0	17	.13	
	8	6.6	11	.11	
120 lbs. N NH_4NO_3	2			18.33	30%
	4			21.90	36
	12			21.09	33
60 lbs. N $(NH_4)_2SO_4$*	5			.07	
	7			.07	
	10			.08	

* No measurable NH_3-nitrogen leached.

Channeling of water probably accounted for some of the erratic variation between replicates. But, in general, it appears that conversion or fixation of urea during the leaching period reduced its relative mobility to about one-half that of an equivalent amount of nitrate nitrogen. Obviously, any factor enhancing or retarding the rate of conversion of urea to ammonia would be a major consideration in determining the degree of leaching that would take place as a result of rainfall immediately following fertilization.

Data showing the relative conversion rates for urea in various soils are given in Table 2. They were obtained by adding urea nitrogen to fresh soils held in field moist condition for a period of not over two weeks until tests could be completed. One hour tests were made by adding urea to suspensions of 1:4. soil:water, while 22 and 68 hour tests were made in soils held approximately at field capacity moisture content during the incubation period. In each case, the soil was extracted at 1:4 dilution using calcium sulfate to aid filtration. Calcium carbonate was added to the filtrate to precipitate copper if present, and the filtrate was divided one-half for direct distillation of ammonia and the other digested with urease for one hour before distillation. The difference represented urea nitrogen.

TABLE 2.—Conversion of 60 p.p.m. of Urea-Nitrogen Added to Various Soils.

No.	Soil	Total Copper Lbs./A.	Soil pH	Percentage of Urea Converted			
				In 1 Hour	In 22 Hours	In 68 Hours	Plus** Urease 1 Hour
	Leon f.s.						
1571	In celery	300	6.3	10	53	100	94
1573	In celery	1000	6.8	13	86	100	88
1574	In cabbage	*	6.5	12	81	100	51
1576	In celery	400	7.3	11	29	100	32±14
1575	In glads		6.9	9	95	100	100
1570	Virgin		5.6	23	99	100	100
1499	Virgin		4.7	58	99	100	100
	Lakeland f.s.						
1510	In citrus	545	6.2	0	40	100	15
1513	In citrus	174	6.4	2	32	98	66±9
1512	In citrus	12	4.6	16±6	14	45	37±6
1455	Virgin		5.1	28	100		100
1455	Subsoil		5.9	4	67		100
	Rutlege f.s.						
1482	In potatoes		5.0	16	98		99
1483	Virgin		4.9	13	56		100
	Red Bay f.s.						
1506	Cultivated		6.2	8	82±11		98
	Rockdale f.s.l.						
1501	Cultivated		8.1	36	99		100
	Perrine Marl						
1505	Cultivated		8.2	13	83		100
	Norfolk f.s.l.						
1507	Cultivated		5.5	4	75		89

These data reported in part in Fla. State Hort. Soc. Proc. (4). High copper soils supplied by I. W. Wander and P. J. Westgate. Variation between 2 or 3 replicates was ± 4 or less except as shown.

* Chlorotic cabbage indicated high copper in old celery field.

** Urease enzyme was added to the soil and shaken 10 minutes before adding urea.

With one set of tests, those indicated in Table 2 by the heading "Plus Urease, 1 hour," .06 gm. of Jackbean meal was added to the suspension and shaken 10 minutes before adding the urea for the one hour conversion period. This was used as a measure of the ability of the soil, or specifically the soluble copper, to inhibit the activity of urease. The ability of various soils to convert urea varied widely. In all instances, except where urease was added initially, the majority of the urea still remained at the end of one hour. Cultivated soils in which copper sprays had not built up residues converted practically all of the urea in 22 hours time.

In the case of soils where the use of copper sprays had been a common practice the conversion of urea in 22 hours was retarded, markedly so in some instances; but in only one instance, R 1512, was a detectable amount of urea found to persist for 68 hours. This occurred where copper was relatively low. However, the strong acidity would tend to make copper more soluble. That an inhibitor of urease was present is demonstrated by the low efficiency of urease added to soils before the urea was put into the suspension. It is well known that copper and certain other heavy metals are inhibitors of urease. A further test of this inhibition of urease by copper is given in Table 3 where various amounts of copper sulfate were added to a calcium sulfate extract of a soil carrying no copper residues. The data show that as little as 0.2 pound of copper in solution per acre plow depth would be appreciably inhibiting to urease activity, thus supporting the contention that copper was the specific inhibitor in the case of the soils containing copper residues. It appears that the presence of copper could markedly increase the potential for movement of urea in a given soil by reducing the rate of conversion of urea to ammonia.

TABLE 3.—Inhibition of Urease by Copper Sulfate Added to Calcium Sulfate Extracts of Fellowship Loamy Fine Sand and Digested One Hour.

P.P.M. Copper in Extract	Percent Conversion of 117 p.p.m. of Urea Nitrogen Added to Extract	
	0.12 Gm. Jackbean Meal/100 Ml.	0.06 Gm. Jackbean Meal/100 Ml.
0	99.7	99 7
0 064	91.6	81.6
.128	74.0	47.7
.32	51.8	25.0
.64	22.7	15.9
1.60	15.7	9.6

The fixation of urea as such, or retardation of leaching of urea is difficult to determine because of the complex chemistry involved and the rapidity of conversion processes. No specific information on the fixation of urea in a form non-convertible by urease has been obtained as yet in these investigations. However, there is some indication that appreciable sorption of urea in a form readily convertible by urease may exist. Up to 30 pounds of urea nitrogen was held by weak fixation in some tests, but further studies are needed to determine the significance of these processes.

As previously stated, ammonia may be held in some soils in a form that is relatively slowly replaced by other bases. Initial studies indicated that appreciable amounts of the nitrogen applied as urea were not recoverable by replacement with 10 percent sodium chloride solution after sufficient time elapsed for conversion to ammonia. To examine this phenomenon solid ammonium bicarbonate was added to moist Perrine marl, Leon fine sand and Arredondo fine sandy loam. Asperation of air in the reaction flasks through standard acid indicated no significant error due to gaseous loss of ammonia. The soils were allowed to stand 18 hours, then various portions were extracted with 10 percent NaCl solution or by direct distillation from the soil in a solution containing sodium chloride and sodium hydroxide. Nitrification was measured and found to be negligible during the 18 hour period.

TABLE 4.—Fixation of NH_4HCO_2 in 18 Hours Against Extraction by NaCl Solution or Direct Distillation with NaOH Plus NaCl.
(All values on moist soil basis)

Soil	P.P.M. Nitrogen Added as NH_4HCO_3 (17.8% N)	P.P.M. Nitrogen Not Recovered: 10% NaCl 1 to 8 Susp. 30 Minutes Extraction	Direct Distillation from 100 G. Soil and 400 Ml. 2½% NaCl Plus: 1 Gm. NaOH	2 Gm. NaOH
Leon Fine Sand pH 4.2 7% Moisture	1200	103	94	83
	1000	67	67	59
	800	40	36	43
	600	32	33	28
	400	17	26	19
	200	11	16	10
Everglades Perrine Marl pH 8.0 32% Moisture	1200	40	64	60
	1000	32	79	77
	800	22	59	37
	600	26	37	38
	400	16	25	34
	200	16	23	17
Arredondo Fine Sandy Loam* pH 6.6 18% Moisture	1200	137	146	110
	1000	117	122	94
	800	83	71	81
	600	62	58	Lost
	400	48	40	41
	200	28	25	23

Blanks Deducted to Obtain Above Values

Leon	0	3	18	39
Marl	0	3	61	110
Arredondo	0	3	7	35

* Blue and Eno(2) found no measurable fixation of ammonia in Arredondo loamy fine sand using a somewhat different technique.

Data given in Table 4 show that appreciable amounts of ammonia were not recoverable by the extraction or distillation methods used. These methods are arbitrary as measures of fixed ammonia, but they do indicate that the amount of ammonia so held might be significant in retarding availability of the applied nitrogen. It is interesting to note that values obtained by the different methods for certain of the soils approximate each other after deduction of respective blanks.

The percentage of applied ammonia fixed for the different quantities applied was found to be remarkably uniform in general. This suggests that a relatively definite ratio of fixed to replaceable ammonia exists. It may be accounted for by the method of fixation used in which dry ammonium bicarbonate salt was mixed with moist soil. The nature of such a mixture would be to create micro-zones of concentrated ammonia regardless of quantities applied, and produce similar potentials for fixation. On the other hand, this factor probably also accounted for the lack of exact consistence of data in some instances. Any differential heterogeneity of mixing that did exist would produce somewhat different ratios of fixed to exchangeable ammonia. Repeated trials showed the same general trends, but different degrees of heterogeneity of data. The data reported in Table 4 are typical of a single series of tests.

These data should not be interpreted as giving a measure of availability of ammonia, because the chemical methods are arbitrary and correlation with plant and microbiological responses have not as yet been established. They do indicate that further studies involving biological availability are in order. It should be pointed out that the larger quantities of nitrogen used are realistic for such concentrations of ammonia as exist when heavy band fertilization is practiced.

TABLE 5.—AMMONIA BUILD-UP IN SEVEN DAYS IN THE VICINITY OF UREA BANDED IN VARIOUS SOILS AT FIELD CAPACITY MOISTURE.

Soil	Soil No.	P.P.M. NH_3-Nitrogen at Various Distances from Placement*	
		1 - 2 Inches	2 - 3½ Inches
Lakeland f.s.			
Virgin	1480	50	2
Virgin	1455	77	0
In citrus	1456	21	0
In citrus	1510	8	0
Leon f.s.			
Virgin	1499	31	0
Red Bay f.s.l.			
Cultivated	1506	64	0
Perrine Marl			
Cultivated	1505	0	0

* 143 mgms. urea-nitrogen was spread over an area of 11.3 square inches and vertical diffusion both up and down measured.

The possible significance of diffusion of urea from the zone of banding was examined by placing bands of urea in soil at field capacity moisture and then determining the quantity of ammonia present at various distances from the band at the end of seven days time. It was realized eventually that the process of fixation of ammonia discussed in the preceding section was a major limiting factor in interpreting the data, and accurate conclusions would have to depend on an evaluation of fixation processes proceeding simultaneously with diffusion. As a result of the trials reported in Table 5. the majority of which were conducted in triplicate. it was possible to conclude that diffusion of nitrogen into the 1 to 2 inch zone was appreciable in many instances, but apparently did not exceed two inches from the zone of placement.

CONCLUSIONS

The results of this study indicate that 60 p.p.m. of urea nitrogen existed as such for only a relatively short period after application to the soil—about one day for a normal soil but less than three days for less active soils. The slower rates occur with certain virgin soils, subsoils or soils having appreciable copper residues. The effect of concentration of urea, as in band placement, is yet to be explored.[1]

An important consideration is the reactivity of the alkaline form of ammonia resulting from the conversion of urea. Not only does it react readily with hydrogen on the base exchange complex, but fixation of ammonia in difficultly replaceable form may be of significance in producing retarded availability and increased resistance to leaching.

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[1] Unreported data on cultivated Lakeland fine sand in use for general farm crops showed a maximum conversion of 1800 p.p.m. of urea-nitrogen (8000 pounds of urea per acre plow depth) in 66 hours.

RESPONSE OF PECANS TO TIME AND RATES OF NITROGEN AND POTASSIUM FERTILIZATION

Nathan Gammon, Jr., and Ralph H. Sharpe*

In investigating pecan production, Hagler and Johnson(6) concluded that of all the major elements studied the percentage of nitrogen in the leaves was most closely associated with yields. When the nitrogen content of the leaves dropped below 2.0 percent, average yields were less than 15 pounds per tree; while trees with an average leaf nitrogen content of 2.27 percent had average yields in excess of 56 pounds of nuts per tree. Higher calcium values were frequently associated with the highest yields but the relationship was non consistent. They found no significant differences in potassium, magnesium or phosphorus in any of their yield classes.

The authors have been sampling pecan foliage extensively over the past six years(11). Variations between years and time of year have been considerable; however, the bulk of the samples used for comparative purposes have been taken in September. Severe winter injury was observed on pecans(10) when the potassium level in the leaves dropped below 0.41 to 0.48 percent during the preceding season when the trees were bearing a crop, and ranged from 0.68 to 0.70 percent when the trees were barren the succeeding season. No yield increases were noted(8) when potassium levels in the leaves were above 0.74 percent in a bearing year. The potassium levels of these same trees ranged from 0.88 to 1.16 percent in a non-bearing year. Good yields were reported by Hunter and Hammar(7) on trees with leaf potassium level of 0.60 percent in heavy crop years.

Magnesium deficiency symptoms were found in the range of 0.08 to 0.20 percent magnesium(9) and limited observations indicated no serious yield reductions as long as the trees were not defoliated. No yield increases were obtained when the magnesium content of the leaves varied from 0.39 to 0.47 percent(8). Leaf phosphorus content has varied from 0.12 to 0.35 percent without observable association with yield differences. Hunter and Hammar(7) reported good bearing trees with levels as low as .09 percent P in the leaf samples taken in September of a heavy crop year.

When nominal rates of fertilization are initiated on trees growing on relatively low fertility levels, it has been a general observation that several years of fertilization were required before the level of nutrients in the leaves of pecan trees would contain a significant increase over those on the unfertilized trees. However, improvement in growth or general appearance was usually noted in the first or second year. These experiments were designed to increase the nutrient level (especially nitrogen) in the pecan leaves as quickly as possible, with the assumption that the

* Soils Chemist and Associate Horticulturist, respectively, Florida Agricultural Experiment Station, Gainesville.

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sooner the nutrient level was improved the sooner the yield potential would be increased.

Previously reported experiments in Florida (1, 2, 3) have included fertilizer which supplied as much as 4 pounds of N and $2\frac{1}{2}$ pounds of K_2O per tree, although the usual amount seldom exceeded half of these rates. In some experiments, additional nutrients were supplied through cover crops or from residual fertilizer from an intercrop of corn, cotton or vegetables. From experiments in Louisiana(4), it was recommended that pecan trees approximately 40 years old be supplied with nitrogen at the rate of 6 pounds per tree per year. It may be reasoned that the nitrogen requirements of pecan trees in Florida, growing on sandy, low-organic matter soils, would be equal to, or higher than, those found in Louisiana. Likewise, trees growing on a low nitrogen level would require more than the average maintenance level if the soil and the tree were to be brought quickly to a high level of nutrition.

EXPERIMENTAL

Single-tree plots, matched for tree size and replicated six times, were established in the spring of 1954 on a Rex-Blanton fine sand complex near Earleton, Florida. The trees were of the Curtis variety, about 35 years old, planted on a 50′ x 50′ spacing, and the orchard was known to have a below-average nitrogen supply. Single-tree treatments were 4, 8 or 16 pounds of nitrogen as ammonium nitrate or 4, 8 or 16 pounds of K_2O as muriate of potash, respectively, applied March 16, 1954 to the area under the branch spread of the tree. These plots were not refertilized in 1955 but additional trees not previously fertilized were treated with the 8 or 16 pound rates of N or K_2O, respectively, on January 18, 1955.

A second experiment was designed to determine the effects of time of application on subsequent response of the pecan tree. Treatments included three application dates: December 15, 1954, February 1, 1955, and March 15, 1955; using 10 pounds per tree of N or K_2O, or both, with three replications on Curtis variety on a Rex fine sand, near Orange Heights and three replications on Stuart variety on an Archer-Hernando fine sand complex near Branford. The Orange Heights orchard was considered to be on a low level of nitrogen supply while the Branford orchard was low in both nitrogen and potassium.

RESULTS AND DISCUSSION

The trees fertilized with nitrogen in the first experiment exhibited considerable improvement in leaf color within 60 days after the fertilizer application. Practically no crop was set in the orchard in 1954 but there was an indication in July, Table 1, that the fertilization had stimulated some nut set. However, by the end of August, the few nuts set had been destroyed by insects or other pests.

A good crop was set in the spring of 1955 and with the possible exception of drought damage(5) to one replication, the crop was carried to maturity. Trees fertilized with 16 pounds of N in 1955 suffered most severely from limb breakage. Yield and quality analyses of the nuts have not been completed.

TABLE 1.—EFFECT OF FERTILIZATION ON SET OF PECAN NUTS PRIOR TO SEASON WHEN NO YIELD IS EXPECTED, CURTIS VARIETY.

Treatment	No. of Trees in Treatment	No. of Trees Which Set Some Nuts
N fertilizers only	18	7
K fertilizers only	18	3
No fertilizer	6	0
All other trees in orchard not fertilized	79	3

TABLE 2.—EFFECTS OF NITROGEN AND POTASSIUM FERTILIZATION ON MINERAL CONTENT* OF PECAN LEAVES, CURTIS VARIETY.

Treatment	Sampled Sept. 1954		Sampled September 1955		
	N Percent	K Percent	N Percent	K Percent	P Percent
Check	2.11	1.46	1.92	1.10	0.21
N 4 lbs. 1954	2.25	1.30	2.00	.94	.16
N 8 lbs. 1954	2.42	1.20	2.07	.97	.15
N 16 lbs. 1954	2.47	1.16	2.20	.95	.14
N 8 lbs. 1955			2.21	.98	.16
N 16 lbs. 1955			2.34	.88	.13
K_2O 4 lbs. 1954	2.08	1.67	1.97	1.15	.21
K_2O 8 lbs. 1954	2.06	1.66	1.94	1.09	.20
K_2O 16 lbs. 1954	2.14	1.78	2.02	1.13	.19
K_2O 8 lbs. 1955			1.86	1.17	.18
K_2O 16 lbs. 1955			1.86	1.29	.19
L. S. D. (.05 level)	.12	.21	.12	.17	.02

* Oven-dry basis.

TABLE 3.—EFFECT OF TIME OF FERTILIZER APPLICATION ON APPEARANCE* OF PECAN FOLIAGE IN APRIL.

Time of Application	Fertilizer Treatments			
	Check	N	K	N + K
December 15	3	4.5	3	4.5
February 1	3	4.8	3	4.5
March 15	2	3.2	3	3.3
Average 3 dates	2.7	4.2	3	4.1

* Rated 1 to 5 on basis 1 = poor, 3 = grove average, 5 = best. Each figure is average value for 6 trees except checks are 2 trees.

Leaf samples were taken for chemical analyses each year in September and are reported in Table 2. These rates of fertilization were sufficient to increase the nutrient levels in the leaves significantly the first year. The two highest nitrogen levels remained significantly above that of the check the year after fertilization. Increased nitrogen caused significant reduction in potassium levels in the leaves, but increased potassium did not significantly reduce nitrogen levels in the leaves. Additions of potassium or nitrogen reduced the phosphorus content of the leaves. The lower average levels of potassium and to a lesser degree, nitrogen, in the 1955 analyses is attributed to the fact that the trees were carrying a crop and it has frequently been observed that this depresses the nutrient levels in the leaves.

The second experiment provided some very positive initial responses to time of application and kind of fertilization, Table 3. The nitrogen and nitrogen plus potassium applications provided the biggest improvement in appearance as judged by leaf color and size and twig elongation. Fertilizer applications made by February 1 were more effective than those of March 15 in influencing the early growth and appearance. No great difference between the first two dates was expected, as practically no rain fell during this period.

Observations indicated that a good crop was set on the Curtis trees and a fair crop on the Stuarts. By mid-May the general appearance of the March-15 nitrogen-fertilized trees was about as good as the trees similarly fertilized on the earlier dates, except average leaf size seemed smaller and terminal growth shorter. The nuts on the earlier nitrogen-fertilized trees were sizing up most rapidly, the late-nitrogen fertilized trees were intermediate and the check and potassium only trees the least. Further yield observations were halted by the drought which caused the nuts to shed(5) on all trees.

Leaf samples were taken in late June and September. No significant differences, caused by date of fertilization, were noted in the nutrient content of the leaves. The nutrient differences caused by kind and rate of fertilization were similar to those observed in the first experiment and are summarized in Table 4. At least part of the decrease in percentage of nutrients in the leaves between the two sampling dates is attributed to the increased dry weight of the leaves over this period. The differences between the two varieties shown here is primarily attributed to the differences in fertility levels in the two orchards rather than a varietal difference. Varietal differences in levels of nutrients in the leaves have been suspected, but when the varieties are grown under identical conditions the differences are relatively small.

It is of interest to note that the level of K in leaves from the Stuart's was as low as that in winter injured Moore's(10) previously reported. Several trees in this orchard showed killing of top branches typical of those previously observed where potassium was deficient.

The time of fertilizer application, particularly nitrogen, is very important in obtaining a maximum growth response in the early spring on trees previously growing at a low level of fertility. Time of fertilization must be early enough to insure movement of the fertilizer through the soil to the roots prior to the start of spring growth. Since rainfall is relatively low at this period, fertilizer applications by February 1 or

earlier are recommended. Time of application would probably not be so important where high levels of fertility exist except for orchards in grass sod. In this case, the trees would probably be best fertilized in the winter when the grass was dormant and offered the least competition.

TABLE 4.—EFFECTS OF NITROGEN AND POTASSIUM FERTILIZATION ON MINERAL CONTENT OF PECAN LEAVES IN JUNE AND SEPTEMBER.

Treatment	Variety	June Sample		September Sample		
		N Percent	K Percent	N Percent	K Percent	P Percent
Check	Curtis	2.39	1.52	2.22	1.38	0.17
N 10 lbs.	"	2.66	1.71	2.42	1.17	.15
K_2O 10 lbs.	"	2.29	1.66	2.18	1.51	.17
N + K_2O	"	2.59	1.85	2.30	1.51	.15
Check	Stuart	1.84	.60	1.52	.57	.20
N 10 lbs.	"	2.16	.54	1.69	.46	.15
K_2O 10 lbs.	"	1.69	.78	1.60	.54	.13
N + K_2O	"	1.87	.74	1.93	.63	.11
L. S. D. (.05 level)				.12	.18	.02

CONCLUSIONS

1. Pecan trees on relatively low fertility levels will show a significantly increased nutrient level in the leaves the first year if sufficiently heavy fertilizer applications are made in the winter or early spring.

2. The biggest visual response is caused by nitrogen fertilization.

3. On low-fertility groves, the best time of fertilizer application for maximum initial growth is February 1 or earlier.

4. Up to 16 pounds of N per tree can be safely used to stimulate growth in a year when no sizeable nut crop is anticipated. But the rate probably should be limited to 8 pounds preceding a heavy crop year to avoid severe limb breakage.

5. These experiments have not run long enough to determine quantities of nitrogen necessary to maintain levels in the leaves commensurate with those found in high yielding groves, but it appears that mature trees planted at 12 to 17 trees per acre will require 6 to 8 pounds of N per year per tree from fertilizer and/or cover crop sources.

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THE EFFECT OF NITROGEN SOURCE ON THE YIELD AND QUALITY OF VEGETABLES

C. M. Geraldson and D. G. A. Kelbert*

Crop plants require nitrogenous fertilizers in comparatively liberal quantities to make satisfactory growth. Nitrogen can be absorbed and assimilated by plants as either nitrate or ammonium. Tiedjens and Robbins(11) growing tomatoes, soybeans and peach seedlings in sand cultures concluded that ammonium was most efficiently assimilated at pH 7.0 or above, while nitrates were most efficiently assimilated at a pH between 4.0 and 5.0. Ammonium, although absorbed, was not assimilated at pH 4.0.

It is generally believed that when ammonium is used in fertilizers. a large portion is converted to nitrates and thus both ammonium and nitrate nitrogen are available to the plant. In some cases excess ammonium has been considered toxic. Lorenz(6) noted that anhydrous and aqua ammonia caused injury to several vegetable crop plants and related it to the greater movement. compared to ammonium sulfate, in alkali soils. The right combination of conditions for ammonium toxicity would be rather rare in Florida.

Several investigators(9. 12) have pointed out that nitrate sources of nitrogen raise the soil pH. while a source such as ammonium sulfate lowers the pH. Volk and Tidmore(12) using different nitrogen sources on a number of soil types (sandy loam to clay) found that in most cases the non-acid-forming sources were superior to the acid-forming sources for the production of cotton and corn. When the acidity of the acid-forming sources was corrected. these differences were eliminated at most sites.

Calcium nutrition has often been associated with nitrogen source. Several investigators(4, 5, 10) have concluded that a nitrate source of nitrogen causes an increased production of organic acids by the plant, which in turn is associated with an increased uptake of calcium. Lyon et al(7), working with various combinations of cations and anions in sand cultures, concluded that greatest fruitfulness of tomatoes occurred in treatments relatively high in nitrogen and calcium.

The preceding brief summary serves as a background for the research and results described in this paper. This experiment was conducted to determine the effect of different nitrogen sources on the yield and quality of a number of vegetable crops.

RESULTS

A Bradenton fine sandy soil that had been used for production of vegetable crops for many years was chosen for this experiment. The irrigation and drainage was provided by tile placed 18 to 24 inches deep,

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* Assistant Soils Chemist and Associate Horticulturist, respectively, Gulf Coast Experiment Station, Bradenton.

just above the hard pan. Sodium nitrate ($NaNO_3$), ammonium nitrate (NH_4NO_3) and ammonium sulfate [$(NH_4)_2SO_4$] were used to supply equivalent amounts of nitrogen. Five different vegetable crops, each replicated 3 times, were grown each season. Ten crops, fall and spring, were grown each year for the past 4 years. Crops were rotated each season. Organic sources of nitrogen such as summer cover crops were limited as much as possible and plant refuse was removed after each crop season.

Dolomite was applied as needed to maintain a pH of about 5.8 to 6.0. After the first crop year no organics were included in the fertilizer and an 8-6-8 analysis was used instead of 4-8-8. An attempt was made to supply an adequate amount of nutrients at all times. Pathologically, damping off was probably the most serious difficulty. Occasionally nematodes caused some damage. Physiological disorders sometimes associated with nitrogen source materials were not a problem.

Yields of 8 tomato crops are presented in Table 1. Fruits were graded, held in storage and checked for firmness and ripening characteristics. Many were sliced to determine possible internal differences. Consistent differences in quality were not found regardless of the measuring standard used. Average size of fruit was found to be slightly larger with the ammonium nitrate source during several seasons.

Yields from 5 cucumber crops are presented in Table 2. Cucumbers were graded and measured for color, firmness, length and internal quality. The different treatments had no measurable effect on fruit quality in any manner that could be measured. The prevalence of bottle neck or underdeveloped cucumbers could not be correlated with any particular treatments.

Yields from 6 sweet corn crops are presented in Table 3. The sodium nitrate plots produced consistently poorer quality sweet corn. Maturity was less uniform, husk color and cover was poorer and average length of ears as well as weight were less than that produced with the other two nitrogen sources.

Yields from several other vegetable crops which responded similarly to those in preceding tables are presented in Table 4. Quality measurements which included grading, external and internal characteristics before and after storage were checked on all crops. Generally poorer quality was associated with lower yields and thus most consistently with the sodium nitrate source of nitrogen.

The results with cabbage did not follow the pattern of response to nitrogen source as indicated in the preceding tables. Yields from this crop are presented in Table 5. Consistent quality differences could not be associated with any nitrogen source material.

Of the 7 vegetable crops grown at least two or more seasons, pole beans and sweet corn yields and quality, were most consistently affected adversely by the sodium nitrate source of nitrogen. In terms of yield and quality, pole beans were best with ammonium nitrate and corn best with ammonium sulfate. Cucumbers might be rated with corn and pole beans except that response was not consistent each season.

A second group which also tended to respond similarly to these nitrogen sources but to a lesser degree included tomatoes, peppers and canta-

TABLE 1.—Yields of Tomatoes as Affected by Nitrogen Source.

Nitrogen Source	Total Marketable Fruit (Bushels/Acre)								
	Fall 1951	Spring 1952	Fall 1952	Spring 1953	Fall 1953	Spring 1954	Fall 1954	Spring 1955	Average*
$NaNO_3$	407	178	382	286	440	606	602	484	423
NH_4NO_3 ..	442	190	416	362	472	686	698	595	482
$(NH_4)_2SO_4$	445	199	359	318	484	655	644	566	459

* Differences not statistically significant.

TABLE 2.—Yields of Cucumbers as Affected by Nitrogen Source.

Nitrogen Source	Total Marketable Fruit (Bushels/Acre)					
	Fall 1951	Spring 1952	Fall 1952	Spring 1953	Fall 1953	Average
$NaNO_3$	149	34	360	333	251	226
NH_4NO_3	219	102	337	452	286	280
$(NH_4)_2SO_4$	216	101	306	411	302	267
L. S. D.						35**

**Significant at the 1% level (similar designation pertains to all following tables).

TABLE 3.—Yields of Sweet Corn as Affected by Nitrogen Source.

Nitrogen Source	Total Marketable Ears (Crates/Acre)						
	Fall 1951	Spring 1952	Fall 1952	Spring 1953	Fall 1953	Spring 1954	Average
$NaNO_3$	106	67	124	194	168	236	156
NH_4NO_3	139	96	156	226	224	308	199
$(NH_4)_2SO_4$	169	112	160	228	232	316	210
L. S. D.							21**

TABLE 4.—Yields of Pole Beans, Cantaloupe and Peppers, as Affected by Nitrogen Source.

Nitrogen Source	Total Marketable*					
	Pole Beans (Bushels/A.)		Cantaloupes (Crates/A.)		Peppers (Bushels/A.)	
	Spring 1954	Fall 1954	Spring 1953	Spring 1954	Fall 1951	Spring 1953
$NaNO_3$	288	224	149	306	228	90
NH_4NO_3	456	336	160	434	262	114
$(NH_4)_2SO_4$	368	328	136	365	265	120
L. S. D.	51**	25**	....	57**	....	20**

* Because each crop was grown only 2 seasons, statistical analysis is included for each season.

TABLE 5.—Yields of Cabbage as Affected by Nitrogen Source.

Nitrogen Source	Total Marketable (Tons/A.)				
	Spring 1952	Fall 1953	Fall 1953	Fall 1954	Average
$NaNO_3$	27.3	19.0	18.0	12.2	19.1
NH_4NO_3	24.9	18.6	20.4	12.4	19.1
$(NH_4)_2SO_4$	25.0	19.3	19.2	11.0	18.6

TABLE 6.—pH, and Amounts of Nitrate and Ammonia Nitrogen in Soils Fertilized with Different Nitrogen Sources.

Nitrogen Source	pH	Nitrogen			
		Pounds per Acre		p.p.m. in Soil Solution	
		NO_3	NH_4	NO_3	NH_4
$NaNO_3$	6.0 - 6.5	26.7	4.8	188	3
NH_4NO_3	5.5 - 6.0	25.4	11.1	126	38
$(NH_4)_2SO_4$	5 2 - 5.7	19.1	15.0	75	41

TABLE 7.—Average Yields of Sweet Corn, Pole Beans, Cucumbers, Tomatoes and Cabbage as Affected by Four Nitrogen Sources.*

Nitrogen Source	Sweet Corn Crates/A.	Pole Beans Bu./A.	Cucumbers Bu./A.	Tomatoes Bu./A.	Cabbage Tons/A.
$NaNO_3$	181	216	315	428	18.5
NH_4NO_3	229	316	359	484	19.5
$(NH_4)_2SO_4$	234	268	339	454	19.2
$Ca(NO_3)_2$	187	296	308	438	18.0

* The calcium nitrate comparison was continued for four crop seasons beginning with the fall crop in 1952 and ending with the spring crop of 1954.

loupe. On the basis of only one season's results, onions and squash might be included in this group.

One crop, cabbage, did not show any consistent differential response to any nitrogen source material. On the basis of one season's results, lettuce and eggplant might be included in this group. Carrots, on the basis of the single crop grown, was in a category by itself in that yields from the sodium nitrate and ammonium nitrate fertilized plots were superior to those fertilized with ammonium sulfate. Regardless of the crop, the variation due to nitrogen source was not affected by the spring or fall season or from year to year. Sweet corn yield variations due to nitrogen sources were consistently decreased in a replicate that was placed on the wetter end of the field. This might be explained on a basis of the prevalence of a higher proportion of ammonium nitrogen in the soil than in the drier replications. Generally speaking, superior quality was consistent with highest yields.

Results obtained in this experiment are not in agreement with results obtained in Alabama by Volk and Tidmore(12). Using cotton and corn they concluded that the non-acid-forming source of nitrogen such as sodium nitrate were superior to the acid-forming sources such as ammonium sulfate. When acidity of the acid-forming sources was corrected, the differences were eliminated. The soil pH obtained in Alabama was almost identical to the resultant pH in the experiment described in this paper. The pH ranges for the different nitrogen sources are presented in Table 6. The pH range indicated was consistent for each source material regardless of crop or season. The pounds per acre nitrogen was extracted with sodium acetate. Figures given are averages of 22 samplings taken during the 51-52 crop season. The p.p.m. in the soil solution nitrogen was extracted with water from a saturated soil solution. Figures given are averages of 14 samplings taken during the 1955 spring crop season. Results obtained in this experiment would approach those attained using sand or nutrient cultures where nitrate nitrogen was more efficiently utilized at a pH of 4.0 to 5.0(11). A relatively high pH and the predominance of nitrates in the soil caused by the all-nitrate sources, theoretically is not a good combination for efficient utilization of nitrogen.

TABLE 8.—THE CALCIUM, NITROGEN AND MANGANESE CONTENT OF SEVERAL VEGETABLE CROPS AS AFFECTED BY NITROGEN SOURCE.*

Nitrogen Source	Pole Beans						Carrots					
	Old Leaves			Young Leaves			Top			Root		
	Ca	N	Mn	Ca	N	Mn	Ca	N	Mn	Ca	N	Mn
$NaNO_3$	5.01	2.98	22.6	1.88	4.69	11.8	2.22	3.48	9.0	0.69	2.88	6.0
NH_4NO_3	5.90	3.45	107.0	1.89	5.44	31.7	2.75	3.81	40.0	.61	2.41	8.0
$(NH_4)_2SO_4$	4.54	3.26	144.0	1.87	5.18	40.9	1.46	3.64	173.0	.55	1.96	22.0
$Ca(NO_3)_2$	4.94	3.37	69.0									

	Tomatoes								
	Mature Leaves			Young Leaves			Fruit		
	Ca	N	Mn	Ca	N	Mn	Ca	N	Mn
$NaNO_3$	2.97	2.91	7.9	0.88	4.66	6.1	0.19	2.59	3.9
NH_4NO_3	3.03	2.46	15.7	1.20	4.83	9.5	.20	3.13	4.3
$(NH_4)_2SO_4$	2.80	2.35	42.7	.87	4.54	16.4	.17	2.38	5.6

* The calcium and nitrogen are given as percent of dry tissue; the manganese as p.p.m. in the dry tissue. Figures given are averages of analyses of 3 replicates from 1 crop and are typical of analyses from similar crops grown during other seasons.

Because more calcium might be required by plants utilizing a nitrate source of nitrogen(10) and because sodium might be causing the adverse effects attributed to sodium nitrate, calcium nitrate [$Ca(NO_2)_2$] was used in one set of plots. Results of this comparison are presented in Table 7. With all crops except pole beans, the response to calcium and sodium nitrate was almost identical. Pole beans seem to be sensitive to accumu-

lations of sodium in the soil. The soil pH range of the calcium nitrate fertlized plots was 5.8 to 6.2.

The dry plant tissue of a number of crops was chemically analyzed for calcium, sodium, potassium, magnesium, phosphorus, nitrogen, chloride, iron, manganese, copper and boron. Some of these analyses are presented in Table 8. Nitrogen results are included to show any differences that might occur because of source material. Because the utilization of nitrates by the plant has sometimes been associated with an increased calcium requirement, calcium results are presented. Manganese results are included because of the consistent variation with regards to nitrate source treatment.

The most consistent effect noted in the tissue analyses in this table was the decreasing manganese content as soil pH increased. The lowest manganese contents were associated with the sodium nitrate source material which produced the highest soil pH. However, the indicated levels are not believed to be a limiting factor. Manganese-deficiency symptoms have been found on tomato leaves when the manganese content in the tissue was 5 p.p.m. or less. Visible manganese deficiencies did not appear in any crop nor did manganese sprays alter results in any way. Response to boron or iron spray has also been negative and tissue analyses have indicated no deficiency or excess.

DISCUSSION

The majority of the crops utilized in this experiment responded more favorably, in terms of yield and quality, to ammonium nitrate or ammonium sulfate than to sodium nitrate. A clear cut explanation of these results is not available, but certain probable contributory factors can be pointed out.

(1) The experiment was conducted on an old vegetable soil which supplied a minimum of organic nitrogen. Regardless of source, the nitrogen supply in the soil was predominantly in the nitrate form. Plants utilize nitrate nitrogen most efficiently at a pH of 4.0 to 5.0. However, a pH of 6.0 to 6.5 was associated consistently with the all nitrate source material in this soil.

(2) Nitrate nitrogen taken up by plants must be reduced within the plant and this process requires energy. Some factors necessary for nitrate reduction include a supply of carbohydrates, a small amount of manganese and a source of light(1, 8). An increased production of organic acids is also associated with a nitrate source of nitrogen which in turn is associated with an increased calcium requirement(4, 5, 10). Young leaves of plants supplied with nitrate nitrogen have been found to contain 3 to 4 times as much nitrate nitrogen as similar tissue from plants supplied with ammonium nitrogen. Such an accumulation would indicate that nitrate reduction might be retarded. Excess nitrates in the plant can be toxic in some cases. From the evidence presented (Tables 7 and 8) calcium was not proved a limiting factor nor sodium a detrimental factor except for pole beans. Although a lower manganese content in the plant was associated with the higher pH and the all-nitrate source materials, it could not be proved a limiting factor.

(3) Another factor which might partially explain results obtained in these experiments is the possible effect of excessive accumulations of soluble salts. The sodium nitrate and ammonium sulfate sources contribute about twice as much soluble material as ammonium nitrate in supplying equivalent amounts of nitrogen. Total soluble salts in the soil solution were determined frequently and only occasionally were found to be excessive. Sometimes, however, they were sufficient to at least be partially responsible for the lower yields associated with the sodium nitrate source material. With some crops this excess may have been sufficient to cause the slightly more favorable response from ammonium nitrate as compared to ammonium sulfate. Pole beans may be such a crop as it has a very low salt tolerance.

Certain general observations should be included in this paper to explain the non occurrence of certain undesirable physiological responses that affect some crops and are sometimes associated with nitrogen source. Such physiological disorders as crease-stem and blossom-end rot of tomato did not occur during any of the 8 crops. Catfacing occurred occasionally but could not be associated with any particular treatment. Puffiness and soft fruit did not occur in any significant quantity regardless of nitrogen source material. Softness in fruit has sometimes been associated with a nitrate source of nitrogen(3) and blossom-end rot with excess nitrogen or an ammonium source of nitrogen(2). Soft fruit causes poor carrying quality and has been associated with a calcium deficiency which in turn has been associated with the use of nitrate of soda or nitrate of soda potash as top dressers(3). Such a top dresser does not include a source of calcium as compared to a fertilizer containing superphosphate. As mentioned previously the utilization of nitrate nitrogen by the plant might also cause an increase in calcium requirement. However, going to the other extreme, an excess of ammonium is known to competitively retard calcium uptake. These same factors are considered important when blossom-end rot is a problem(2). The factors (nitrogen sources) as mentioned above tend to accentuate a calcium deficiency and of course become increasingly more important as the calcium-supplying capacity of the soil decreases. The soil used for the experiment described in this paper has a very high calcium-supplying capacity and this fact aids in explaining why certain physiological disorders, often a problem of commercial growers, were not encountered. As a result of growing these different vegetable crops over a period of 4 years, it is evident that the nitrogen source material is not a primary cause of the undesirable physiological responses.

SUMMARY

During a 4-year period 40 vegetable crops, 5 each season, were grown on field plots receiving different sources of nitrogen. Of the 7 vegetable crops grown at least two or more seasons, pole beans and sweet corn were most consistently affected adversely by the sodium nitrate source of nitrogen. In terms of yield and quality ammonium nitrate was best for pole beans and ammonium sulfate or ammonium nitrate best for corn and cucumbers.

A second group which also tended to respond similarly to these nitrogen sources but to a lesser degree, included tomatoes, peppers and cantaloupe.

One crop, cabbage, did not show any consistent response to any particular nitrogen source.

Generally speaking superior quality was consistent with highest yields which most often were associated with the ammonium nitrate source of nitrogen.

A number of factors associated with the differential response are discussed as probable causes. Factors which affect the most efficient utilization. reduction. and assimilation of nitrate nitrogen by the plant may be important. Excess salts may be a factor which could partially explain the variations in response from the nitrogen source materials, especially with a salt-sensitive crop such as pole beans.

The source of nitrogen was not a factor associated with the prevalence of any adverse physiological responses despite the intensive cropping of this soil. An important consideration in this respect is that this soil has a high calcium-supplying capacity.

On the basis of results obtained, with due consideration for experimental limitations. it is recommended that the "status quo" generally be maintained as regards to nitrogen sources used in mixed fertilizers. If a sandy soil contains a limited amount of organics and has a relatively high pH, an all nitrate source of nitrogen should be avoided for such crops as pole beans, sweet corn, and cucumbers.

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SYMPOSIUM: IRRIGATION PROBLEMS AND CROP RESPONSES IN THE SOUTHEASTERN STATES

Wednesday, November 30, 1:30 P.M.

JOHN W. SITES,* Moderator

STATE-FEDERAL COOPERATIVE IRRIGATION RESEARCH IN THE HUMID REGION**

M. D. THORNE †

Irrigated acreage in the humid regions of the United States increased 70 percent during the period between 1949 and 1954. The expansion of irrigation research activities in such regions has not been adequate and reliable for the sound planning of irrigation programs.

Expanded research on the following items is urgently needed:

1. Determining probability of need for irrigation under various conditions of weather, with various soils, and under different cropping systems.
2. Determining economic response likely to be achieved if irrigation is practiced under the various conditions.
3. Development of adequate water supplies—including such factors as watershed management practices, stream flow characteristics, water storage structures, underground water resources, water quality characteristics, and water laws.
4. Water distribution and application practices—including rates, and frequencies, and amounts of application, efficiency of application, cost of application under various conditions, moisture holding characteristics of soil and consumptive use rates.

Some research is now underway on each of these items but considerable expansion is urgently needed. The irrigation research which is conducted cooperatively between the Soil and Water Conservation Research Branch of the Agricultural Research Service and various state experiment stations in the East is classified under six line projects as follows:

1. Development of water supplies for irrigation.
2. Predicting the need for irrigation from climatological data.
3. Equipment, performance and improvement in design of irrigation systems.
4. Irrigation practices for forage crops.
5. Irrigation practices for cultivated crops.

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* Florida Agricultural Experiment Stations, Gainesville.

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† Soil Scientist, Eastern Soil and Water Management Section, Soil and Water Conservation Research Branch, Agricultural Research Service, Beltsville, Maryland.

6. The water infiltration and storage capacity of soils on agricultural lands.

Currently, there is active work underway on these line projects at the following locations:

Active Locations	Line Project 1	2	3	4	5	6
Alabama				X	X	X
Georgia		X	X		X	X
Maryland						X
Missouri	X		X	X	X	X
Mississippi					X	X
New Jersey	X				X	X
North Carolina		X				X
Pennsylvania				X		X
Puerto Rico			X		X	X
South Carolina		X			X	X
Virginia	X	X	X	X	X	X

It may be noted that no cooperative work is listed in Florida at the present time. A project at Homestead was completed and terminated within the past year but new cooperative work has not yet been initiated.

An elaboration of some work which is underway on each of these line projects might be of interest.

1. *Water Supplies.* Studies have been made in Missouri on the size watershed required for filling of farm ponds needed for irrigation under their conditions. Some work is underway on the sealing and lining of ponds to give maximum conservation of the water which enters the pond. Various types of plastic films are being experimentally used as pond liners in locations in a number of states.

Another important source of water for irrigation in the East is the brackish water which lies along the sea coast. If suitable means could be found for utilization of this water for irrigation of crops, our total water sources would be increased tremendously. A project has recently been installed in cooperation with the Truck Crop Experiment Station at Norfolk, Virginia, to test the utilization of brackish water for vegetable crop irrigation. Various concentrations of salt are being tested for both surface and overhead application.

2. *Climatological Data.* A study has recently been completed in cooperation with North Carolina to provide information on the probability of drought during the growing period. The manuscript for a state bulletin has been prepared and should soon be in print. This study has taken into consideration the moisture holding capacity of various soils in the state and gives information for drought probability as affected by various amounts of moisture storage and by the different regions of the state. This work is now being enlarged to cover the states of Virginia, South Carolina and Georgia in cooperation with the experiment stations of those states. It is hoped that it can eventually be expanded to cover the entire humid region. A somewhat similar study is underway by the Florida Agricultural Experiment Station at Gainesville.

The drought summary work has made use of equations for calculating the consumptive use of crops. These equations are being checked by actual measurements in as many locations as possible. However, the amount of work involved at any location to accurately determine consumptive use is very great so it has not been possible to obtain reliable data from nearly as many locations as is needed and the work must be expanded as personnel and funds permit.

3. *Equipment Testing.* We are currently doing no work on the testing of power supplies and pumps for irrigation purposes in the humid region. At present, we have neither facilities nor personnel to undertake this type of work and are relying on the work done at various state experiment stations and by the commercial companies themselves. Some testing of various sprinkler heads under different wind conditions is underway. Also, the testing of surface versus overhead irrigation in regard to efficiency of water use, man hours required, and crop yields is in progress but needs to be greatly enlarged.

4. *Forage Crop Irrigation.* Experimental data on forage crop irrigation have been obtained at Missouri, Pennsylvania and Virginia. A large scale screening test of forage species is now in progress at Thorsby, Alabama. It is planned that this will be the main location for cooperative forage crop irrigation in the humid region, but supplementary work will still be maintained at the other locations. The services of Engineers, Soil Scientists and Crop Specialists are required for the successful completion of any irrigation experiment. We have been seriously hampered by the lack of personnel at many of our locations, especially the lack of Soil Physicists. It is very important that the irrigation scheduling be done on a precise basis. This requires a detailed knowledge of soil and plant conditions throughout the course of the experiment. The lack of adequate means and adequate personnel for determination of soil moisture in the field is probably our greatest hindrance at the present time. The only method which we now consider reliable is the taking of soil samples in the field and oven-drying them. The work involved is so great, however, that it has not been possible to do this adequately at very many locations. We prefer to schedule our irrigations on the basis of maximum soil moisture tension to be allowed in the root zone. This requires laboratory data on the moisture characteristic curves for the soils and adequate and frequent soil sampling in the field. It is felt that if this type of information can be obtained, the application of the results to other areas will be more accurate.

5. Row-crop irrigation is being done in cooperation with the various states on different crops as tabulated in the following table.

While the number of experiments for row-crops is fairly good there is certainly a need for an enlargement of this program to give more detailed work at these and other locations. There is the same need for detailed soil moisture measurements and the same lack of adequate personnel to provide the information as mentioned above. In many of these experiments it has not yet been possible to schedule the applications on the basis of maximum soil moisture tension. There is also a need for equipment to provide a uniform and accurately determined amount of water to the experimental plots. Some effort has been devoted to this need the past year and a plot irrigator has been devised and built in

cooperation with the Georgia Coastal Plain Experiment Station at Tifton. This is a portable frame work to allow a spray boom to travel back and forth over the top of the plot until the desired amount of water has been applied. Some improvements in this machine are necessary and a great many more of them will be required to cover our experimental program adequately. There seems little point in measuring the response to an application which averages one inch, if the amount on the plot varies from one-half inch to two inches. For example, it is frequently not possible to use over-lapping sprinklers in experimental plots to the extent they might be utilized in a regular field application. Cosequently, the use of this special equipment seems highly advisable. Also, this largely frees the operators of the necessity of making applications in the early morning hours when the winds are generally low, as has previously been the case.

Active Location	Crops						
	Cotton	Corn	Soy-beans	Vege-tables	Sugar-cane	To-bacco	Pea-nuts
Alabama	X						
Georgia	X	X				X	X
Missouri	X	X	X				
Mississippi		X					
New Jersey				X			
Puerto Rico					X		
South Carolina		X					
Virginia		X		X		X	

More cooperative work on the economics of irrigation is needed. This information is difficult to obtain in small plot work and manpower have not generally been available for extending it to the larger scale applications which are required. An expansion of the program would be necessary in order to obtain the amount of this type of information which is needed. This would, of course, be done in cooperation with Agricultural Economists.

6. Some work is underway at most locations on the determination of infiltration and moisture holding characteristics of soil. The detail of the work in most instances is, howover, not sufficient for our purposes and we are expanding this as rapidly as possible. Adaquate means for the easy and rapid determination of infiltration rates are not yet available. Some progress is being made and different types of equipment are being tested. Specialized equipment for determination of moisture characteristic curves is being obtained as rapidly as possible and it is hoped that this equipment will be available to all locations in the near future.

In summary, there is need for expanded research to determine the probability for need of irrigation in the various parts of the humid region, for determining the economics of irrigation, for the development of adequate water supplies, and for developing adequate and satisfactory water distribution and application practices. Excellent progress is being made and the detailed work at specific locations is considered entirely satisfactory in many cases. However, the number of such locations is far too limited and the need for the information is expanding more rapidly than the facilities to provide it.

WATER CONTENT CHANGES FOLLOWING THE WETTING OF BARE SOIL IN THE FIELD*

L. A. RICHARDS **

ABSTRACT

The total amount of water that a soil in the field can supply to growing plants is often talked about, but is not always easy to define precisely or to measure. The expression "available water" may refer, for a soil sample, to the water-content difference between the so-called "field capacity" and the wilting point or, for field soil, may refer to the total available volume of water per unit-area of soil. This is often expressed as surface-depth of water. The lower limit of available water in soil is a reasonably definite quantity that can be defined and measured, but the upper limit is influenced by many factors. Contrary to popular notion, there appears to be no general relation between the upper limit of available water and retentivity values for soil samples removed from the profile. This is illustrated by comparing the water content profiles of two soils following flood irrigation with water retentivity profiles at the 1/3-bar [1] percentage, and at the 1/10-bar percentage, for the same soils.

The 15-bar percentage, however, because of its close correspondence to the wilting point appears to be satisfactory, for agricultural purposes as an index of the lower limit of available water in soil.

* * * * *

Progress is being made toward reducing the flow and distribution of water in the root zone of soil to a problem in hydraulics. The descriptive theory is based on the functional relation of water content to suction and capillary conductivity and on the flow law which states that flow velocity is proportional to the driving force. This hydraulic approach helps to explain observed phenomena and is giving useful answers to practical problems. Since soils are so highly variable, a simplification of soil-water problems is accomplished by directing attention to the water, this being essentially the same in all soils. A theoretical treatment based on the water is, therefore, general in that it can be applied to all soils.

In considering the upper limit of available water in the field it is helpful to clarify the discussion by defining some terms. A physical

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* Contribution from the U. S. Salinity Laboratory, Soil and Water Conservation Research Branch, Agricultural Research Service, U. S. Department of Agriculture, Riverside, California, in cooperation with the seventeen Western States and the Territory of Hawaii.

** Physicist.

[1] The bar is the metric unit of pressure that corresponds to one million dynes per sq. cm. One bar = 0.9869 standard atmosphere = 14.5 pounds per sq. inch and corresponds to 1021 cm. of water at 20 °C and standard gravity. The bar and the atmosphere differ so little that a retentivity measurement at a certain suction, when expressed in bars, would by usual experimental procedures be indistinguishable from the retentivity determined at a numerically equal suction expressed in atmospheres. For scientific work there is advantage in using consistent metric units.

property of soil may be defined as an intrinsic physical quality that can be defined and measured and expressed in numbers, and whose value ideally is independent of the measuring method. That is, any right method will give the same value. The "intrinsic" part of the definition indicates the value of the property is inherent in the thing itself and is not determined by external conditions.

Physical condition has an important bearing on the agricultural use of soil and numerous physical determinations are made with the expectation that they may be usefully related to soil management. Bulk density, porosity, and specific surface are such physical properties. Water retentivity is also a physical property that is defined as the water content of soil at specified suction and structure. Early retentivity measurements were made for sieved samples, partly because soil in this condition is experimentally more tractable and much less expensive to process than core samples. Fortunately it turns out that the lower limit of water available for plant growth, which at present appears to be the most significant single soil-water determination (9), is closely correlated with soil-water retentivity for the suction value of 15 bars. This was established from the correspondence between this retentivity value and the permanent wilting percentage which is a commonly accepted index of the lower limit (7).

The idea that there exists a reasonably definite upper limit of available water for plant growth in the field has long been entertained by soil workers, but the search for a laboratory determination that will correlate with field observations for all soils has not been successful. The reason for this failure has become increasingly apparent with the refinement of a general descriptive theory for the flow and distribution of water in field soil and is resident in the fact that the rate of change of the water content of soil at any given region in the profile is determined not alone by the intrinsic physical properties of the soil in the region under consideration but is determined also by the hydraulic boundary conditions of the region. In other words, the net water-moving force and the resulting flow of water in soil at any given place in the profile in the field is determined in part by properties of the soil at that place but also in part by soil properties and conditions elsewhere in the profile that, in turn, affect the hydraulic gradient at the place in question.

It is of interest to examine some of the single value soil moisture constants that have been associated with available soil water in the field. Among these may be mentioned the 1/3-bar percentage and the 1/10-bar percentage. The data shown graphically in Figure 1 illustrate some of the limitations of laboratory determinations for appraising field moisture conditions.[2] The lower part of the figure presents data for Hanford sand, a soil of such coarse texture that it is near the borderline for successful irrigation in an arid climate. The solid curve is a water content profile and shows the water content of the soil plotted against depth for samples taken one day after the entry of a surface depth of 30 cm. of irrigation water that was applied in a basin to a bare plot. The water retention curve of this soil has been published (5) and shows that the soil pore space is preponderantly of large size. Excess water drains away

[2] The data shown in the figure were obtained over a period of years through the assistance of R. B. Campbell, D. C. Moore, and Gen Ogata.

rapidly in this soil and the water-content profile obtained after one day of drainage represents what might traditionally be taken as the upper limit of the available range. The dashed curves represent water-retentivity profiles, and show the water content of samples taken from various depths in the profile after the samples have been air-dried, screened, saturated with water, and brought to hydraulic equilibrium at the suction values indicated at the bottom of the figure. The retentivity profile for the 1/10-bar percentage lies to the left of the water content profile after one day of drainage and corresponds approximately to the water content profile of this soil after five days of drainage. The 1/3-bar percentage profile lies well over toward the lower limit of the field moisture range as represented by the 15-bar percentage profile. The dashed curve on the right represents the change with depth of the saturation percentage. This is the water content of the soil paste from which solution is extracted for measuring salinity. Standard procedures have been described(8) for the retentivity measurements presented by the four dashed curves.

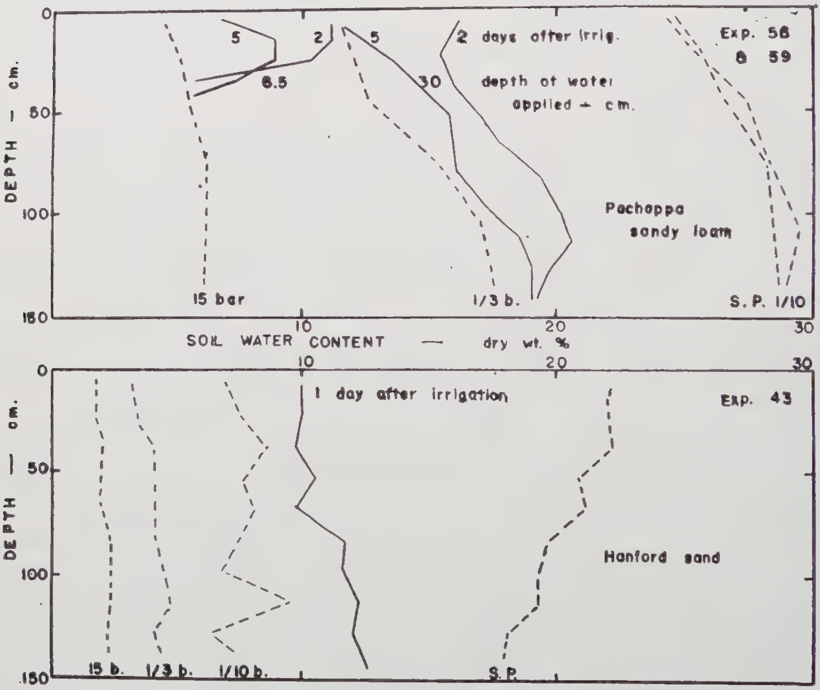

Figure 1. Water characteristics of Pachappa sandy loam and Hanford sand. The dashed curves are retentivity profiles and show the variation with depth of retentivity for the four suction values indicated. The solid curves are field water content profiles on various indicated days following the basin irrigation of bare plots.

The data in the upper part of Figure 1 show water-retention characteristics of the Pachappa sandy loam. Both the Hanford and Pachappa profiles here considered might be described as being deep, uniform, permeable, and well drained. They do not have any pronounced genetic differentiation. The 15-bar percentage for the Pachappa ranges up toward

six at the lower depths and is thus approximately three times the value for the Hanford sand. The two solid curves at the center show water content profiles at two and five days following the entry of a surface depth of 30 cm. of water into a bare plot. It would be somewhat traditional to take the water content profile at the end of two days for this medium textured soil as the upper limit of the field moisture range. For this soil it is seen that the 1/10-bar retentivity profile corresponds closely to the saturation-percentage profile, and that the 1/3-bar retentivity profile lies near the water content profile after five days of drainage.

It is of interest to note, however, the effect of the water distribution in the profile on the so-called upper limit. The two solid curves lying between the 15-bar and 1/3-bar dashed curves are the water content profiles two days and five days following the entry of 6.5 cm. of water into the dry profile. The lower water content values in the wetted zone at these corresponding time values is due to the movement of the wetting front into nearby soil that was initially at or near the 15-bar percentage. It is thous seen that the difference in the depth of wetting caused a difference of about five percent in the water content of the soil as observed in the field soon after irrigation. The proximity of the dry soil increased the downward suction gradient and caused more rapid drianage of the wetted layer. Colman(2) and others have pointed out this dependence of the rate of change of the water content of field soil on the depth of wetting.

The reduced retention of water just reported for the surface layer was produced by the increased hydraulic gradient associated with the steep moisture gradient near the 50 cm. depth. Had there been instead at this depth a water table, or a low permeability layer which would have produced a perched water table, or an abrupt transition to a very coarse textured layer, any one of which would decrease rather than increase the hydraulic gradient, then, the water content of the overlying soil two days following irrigation could have been increased and would have been over toward the saturation percentage. Laboratory determinations for samples from the surface layers would give no indication of the hydraulic effect of such conditions in underlying layers.

The 15-bar percentage, on the other hand, even though it is an intrinsic property of a soil sample, can be used as an index of the lower limit of the available water. This is because the capillary conductivity is very low at this moisture condition and suction value. In the wilting range, soil properties or hydraulic gradient values more than a few cm. away have little effect. It is the root action within a few cm. of the point in question that controls water relations in relatively dry soil. Time, of course, is a factor because the capillary conductivity in the wilting range is distinctly not zero and under certain circumstances may not be negligibly small. For example, it has been shown by Haise *et al.*(3) that under drought conditions in the Great Plains, crops do reduce the water content of soil considerably below the 15-atmosphere percentage and even below the 26-atmosphere percentage.

The centrifuge moisture equivalent was developed by Briggs and McLane(1) as an index of the "relative retentivity" of soil. It has been taken by some to be a direct measure of upper limit of the field moisture range, but this application does not appear to have been intended or at

least was not explicitly claimed by the original authors. Richards and Weaver(7) showed experimentally and theoretically [3] that the 1/3-atmosphere percentage corresponds closely to the centrifuge moisture equivalent but stated, "It is becoming increasingly clear that the moisture equivalent cannot be generally used as an index of either the upper or the lower limit of moisture usable by plants in the field. Moisture equivalent has the advantage of being a definite reproducible quantity not too difficult to determine, but this is insufficient justification for its continued use provided something more closely related to the available moisture range can be found. It is apparent that moisture-retention values in the 1/4- to 1/2-atmosphere ranges are too closely related to moisture equivalent to be of appreciably greater use or significance, except that they are less expensive to determine and they do represent a more definite physical property of the soil moisture."

The 1/10-atmosphere percentage was used by the Bureau of Reclamation [4] for estimating the field moisture range of coarse-textured mesa soils of California and Arizona. During the process of land classification, many thousands of determinations were made, but the measurement was adopted and its interpretation was based on its correlation with water content samplings in the field.

The water remaining in surface layers of soil following wetting is certainly partially determined by the functional relation in such layers of water content to retentivity and capillary conductivity, but also is strongly influenced by factors elsewhere in the profile that determine the hydraulic gradient in the layer under consideration. Wilcox(10), Hanks, *et al.*(4), and many others have proposed laboratory methods for estimating the upper limit of the field moisture range but the applicability of such methods to any particular soil must be checked against field experience.

While the upper limit of the available range is a concept having considerably practical interest, it should be realized that certain soils exhibit a reasonably continuous and sometimes rapid change of water content over a considerable period of time following wetting. Detailed moisture

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[3] The average value of the moisture content Pw of a soil column in the moisture-equivalent centrifuge can be found as follows, provided that the retention curve $Pw = f(S)$ giving the moisture percentage Pw as a function of suction S for soil with centrifuge packing is known. The condition for equilibrium of the soil water is given by the equation $dS/dr = rw^2d$, where r is the radius of rotation, w is the angular velocity, and d is the density of water. The suction S at a point in the soil column at radius r is found by integrating this equation from r_1 at the outflow surface where $S = 0$. This gives $S = \frac{w^2d(r_1^2 - r^2)}{2}$. If $r = r_2$ at the inner surface of the centrifuge column, then

$$Pw = \frac{\int_{r_1}^{r_2} f\left(\frac{w^2d(r_1^2 - r^2)}{2}\right) dr}{r_1 + r_2}$$

This can be evaluated for w, r_1, and r_2 corresponding to the moisture-equivalent case. The suction Sm at which the soil retentivity is equal to the moisture equivalent is then the point on the retention curve corresponding to Pw.

[4] Bureau of Reclamation, Land Classification Report, Gila Project, Arizona, July, 1948. Mimeographed.

samplings for Pachappa soil, without plants(6), has shown that the total water content of surface layers, with or without surface evaporation, is accurately represented by downward sloping straight lines on log-log graph paper when total water content is plotted against time. This relation is expressed by the equation $W = aT^{-b}$ where W is the surface depth of water in the soil layer under consideration, T is the time in days following irrigation, and a and b are constants. From this, it follows that $dW/dT = -abT^{-b-1} = -b(aT^{-b})/T = -bW/T$. In other words, the rate of loss of water from surface layers is proportional to the water content of the layer and is inversely proportional to the time. For such soils it will be difficult, for the designation or measurement of the so-called "field capacity", to choose a time at which moisture loss becomes negligible.

The upper limit of available water will certainly depend upon how rapidly the plant root system can extract and use the soil water during the period immediately following wetting where the rate of loss of water by physical processes may be high. In addition to intrinsic soil properties and hydraulic boundary conditions, the total available water will depend on the climate or weather, and an array of plant factors such as variety, population, and phase of growth of the crop. For example, under extreme weather conditions, the evapotranspiration of a mature crop may approach 1.25 to 1.5 cm. per day. In the first few days following irrigation, therefore, the plants could use several cm. of water that would otherwise be lost from the profile by physical processes, were the crop in the seedling stage.

Expressed on a volume basis, the maximum amount of water a soil profile can possibly contain will be equal to the total pore space, as represented by an integration of the porosity with respect to depth. The amount of water which should be included in the total available water will depend on the depth of the root zone and the water losses from the root zone by physical processes. The latter in turn will depend on the rate at which the water is used by the plant and by the hydraulic properties of the whole profile. For some deep, uniform soils, the upper limit of available water may correlate usefully with retentivity or other intrinsic properties of soil samples, but consideration of the general descriptive theory for the flow and distribution of water in soil leads to the conclusion that hydraulic conditions outside the sampling zone may be controlling factors determining the upper limit and these extrinsic conditions cannot be appraised reliably from samples that are removed from the profile.

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RESPONSE OF FIELD CROPS TO SUPPLEMENTAL IRRIGATION IN TENNESSEE

W. L. Parks *

The extreme droughts during recent years have greatly increased farmer interest in irrigation as a supplement to natural rainfall. A recent survey shows a marked increase in the number of irrigation units. These units are concentrated around the metropolitan regions and in areas of tobacco and strawberry production.

With more and more farmers beginning to use supplemental irrigation, the demand for basic information on the moisture properties of soils and moisture requirement for crops has greatly increased. The current irrigation research carried on by the Experiment Station has three main objectives. These are:

1. To determine the moisture release curves for the major productive soils of the State.
2. To determine the maximum soil moisture tension that may be reached in the root zone of a crop without materially reducing yields.
3. To determine the fertilization requirement of different crops at this moisture tension.

It is obvious that these objectives are broad and that considerable effort must be put forth before the answers are known.

While experiments are underway involving the use of supplemental irrigation on many crops, the results reported herein show the results obtained on Sudangrass in 1954 at the West Tennessee Experiment Station. The data represent the approach taken to the supplemental irrigation problem and the type of information that will be obtained for the different crops under study.

This experiment was conducted to measure the effect of maintaining different minimum soil moisture levels on the yields of Sudangrass on a Lintonia soil. Nitrogen was applied at rates of 30, 60, 90, and 120 pounds per acre at each soil moisture level. Soil tests indicated that the level of phosphate and potash were high. The Sudangrass was seeded in early June and 30 pounds of nitrogen per acre was applied at that time. The remainder of the nitrogen was applied to the various plots prior to the application of the first irrigation treatment.

While it is recognized that it is physically impossible to maintain a soil at a given moisture tension under field conditions, it is possible to prevent the soil moisture tension from exceeding a predetermined value. In this experiment the maximum soil moisture tensions reached before irrigation were 2, 5 and 9 atmospheres. A non-irrigated treatment was also included. Soil samples were collected at periodic intervals and the moisture content determined on an oven-dry basis.

The moisture sorption curves for soil samples collected at the experimental site are shown in Figure 1. The curves represent results for a 0-6 inch sample and for a 6-12 inch sample. It is evident from these curves

* Associate Agronomist, Tennessee Agricultural Experiment Station.

Fig. 1 Moisture Sorption Curves For Two Horizons of A Lintonia Soil

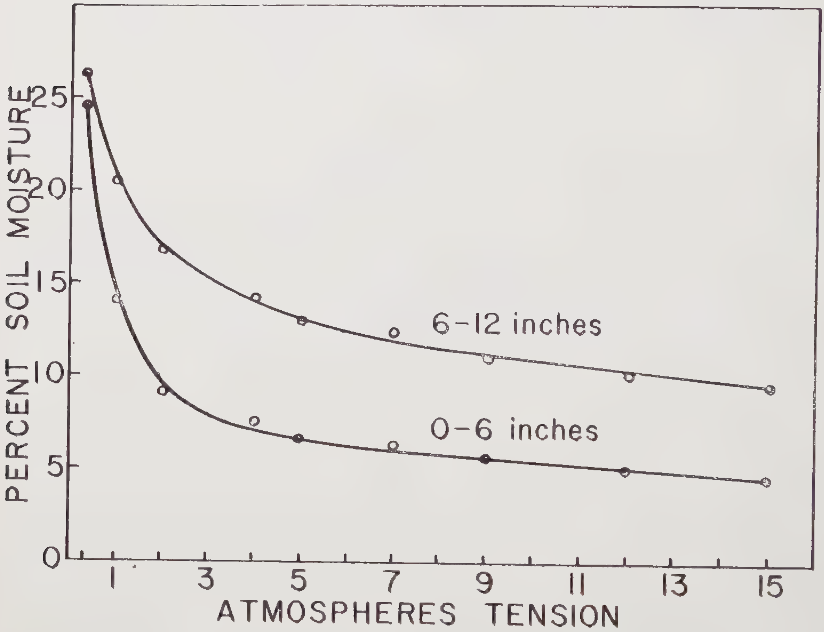

Fig. 2 Relation Between Moisture Block Resistance And % Soil Moisture

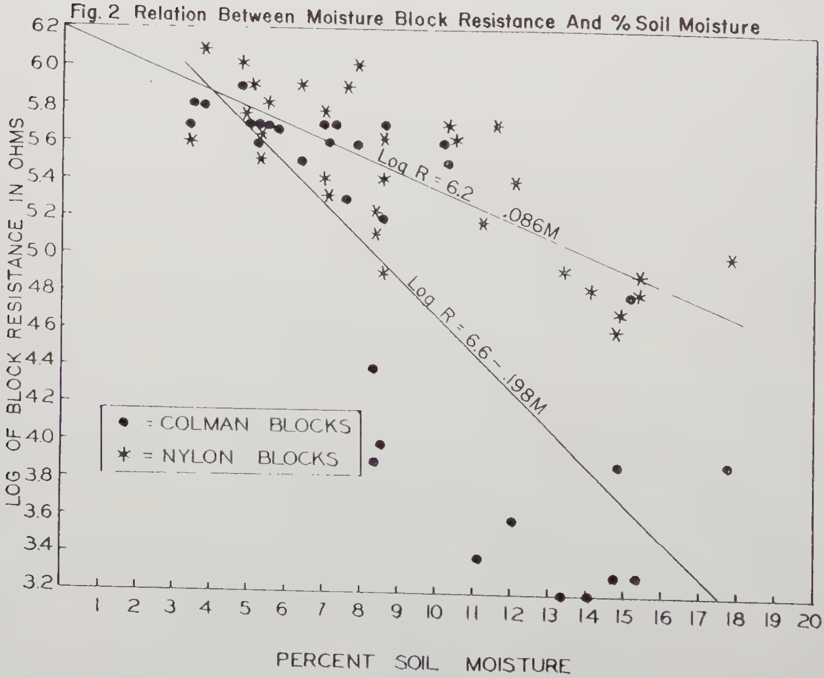

TABLE 1.—IRRIGATION OF SUDAN GRASS FOR FORAGE PRODUCTION. 1954. AVERAGE 4 REPLICATIONS.
(Pounds air-dry forage per acre)

Treatment No.	Irrigation	N Level	1st Cutting 8/3/4	2nd Cutting 8/23	3rd Cutting 9/10	4th Cutting 10/7	Total Four Cuttings
			lbs./A.	lbs./A.	lbs./A.	lbs./A.	
1	No irrigation	30	1008	256	291	398	1953
2	No irrigation	60	982	251	267	498	1998
3	No irrigation	90	905	410	434	395	2144
4	No irrigation	120	942	404	284	436	2066
5	2 atmos. tension	30	1862	827	376	348	3414
6	2 atmos. tension	60	2116	1141	417	422	4097
7	2 atmos. tension	90	2053	1210	416	502	4180
8	2 atmos. tension	120	2069	1222	426	608	4325
9	5 atmos. tension	30	1816	923	553	347	3639
10	5 atmos. tension	60	2052	820	639	395	3906
11	5 atmos tension	90	1777	655	657	407	3495
12	5 atmos. tension	120	2014	955	802	383	4152
13	9 atmos. tension	30	1348	398	299	297	2342
14	9 atmos. tension	60	1726	794	318	382	3220
15	9 atmos. tension	90	1472	778	311	452	3114
16	9 atmos. tension	120	1587	699	386	467	3139

Moisture Means

Moisture Level	Cutting No. 1st	2nd	3rd	4th	Total 4 Cuttings
No irrig.	959	330	319	432	2040
2 atmos. irrig.	2025	1100	409	470	4004
5 atmos. irrig.	1915	838	663	383	3798
9 atmos. irrig.	1559	667	328	399	2954
L. S. D. (5%)	490	289	199	N.S.	649
(1%)	705	415	287	N.S.	933

Nitrogen Means

Nitrogen Level	Cutting No. 1st	2nd	3rd	4th	Total 4 Cuttings
20 lbs N/A.	1509	601	380	348	2837
60 lbs. N/A.	1719	752	410	424	3305
90 lbs. N/A.	1577	763	454	439	3233
120 lbs. N/A.	1653	820	474	473	3421
L. S. D. (5%)	N.S.	145	71	66	314
(1%)	N.S.	193	95	88	421

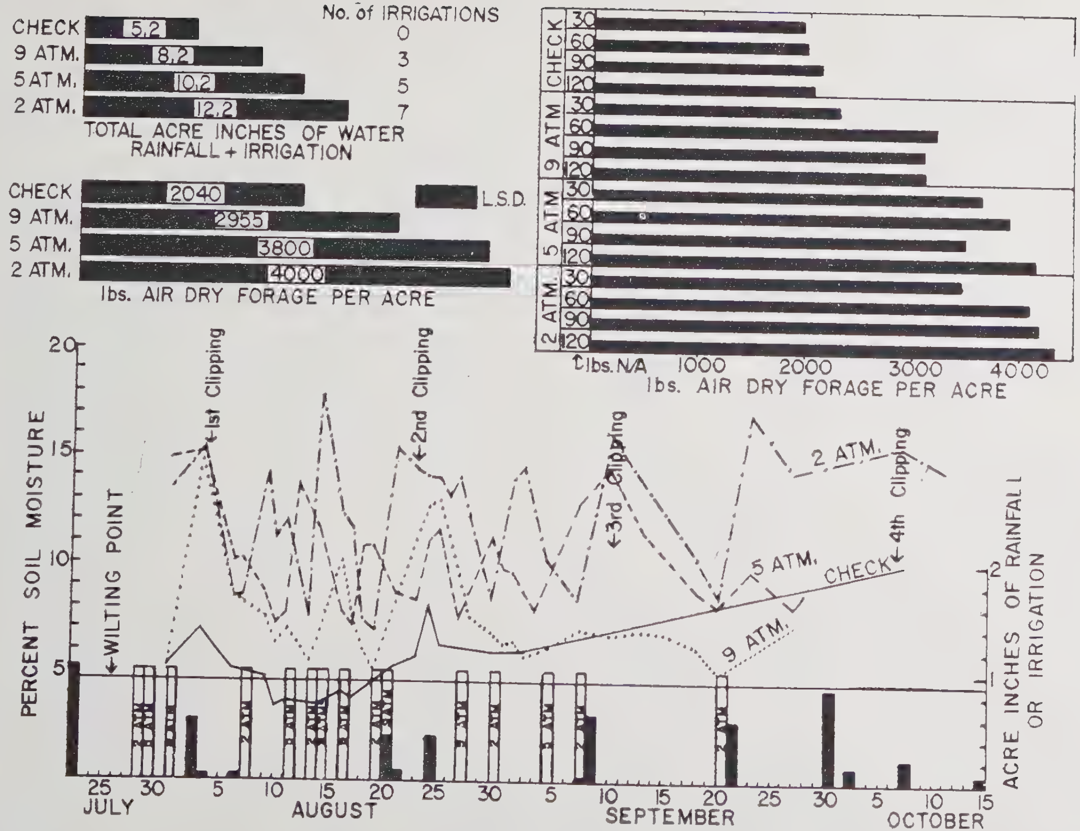

Fig. 3.—Sudangrass, West Tennessee Experiment Station, 1954.

that the 0-6 inch soil zone contains less water at tensions greater than 1 atmosphere than the 6-12 inch soil zone. It is also evident that most of the soil moisture available to plants in this soil is held at tensions less than 6-8 atmospheres.

There was some delay in getting the irrigation system installed and the plots had undoubtedly undergone periods of moisture stress prior to the initiation of the irrigation treatments on July 28. Prior to the initiation of the irrigation treatments, all the plots were clipped and the forage thus removed was not included in the yield results shown in Table 1. These yield results show a significant response to both irrigation and nitrogen but no significant moisture-nitrogen interaction. It required 7, 5, and 3 irrigations of one acre-inch each to maintain the moisture tensions below 2, 5, and 9 atmospheres, respectively, in the 0-6 inch soil zone. The maintenance of moisture tension below 2 atmospheres resulted in a forage yield not significantly different from that obtained when the moisture tension was maintained below 5 atmospheres, but it required two extra irrigations to maintain the lower moisture tension. This is of great economic importance as the two additional irrigations represent an added cost of about 30%. No significant increase from the nitrogen beyond 60 pounds per acre was obtained.

Figure 2 shows the relation between percent soil moisture and moisture block resistance of two different soil moisture blocks. It is evident from the scatter of reference points that the Colman block did not prove to be a reliable indicator of the soil moisture status at this location. The nylon block provided a more reliable means for measuring the soil moisture status of the soil, but even this method left much to be desired. The most reliable measure of soil moisture was obtained by collecting soil samples and determining their moisture contents in the laboratory.

The percent soil moisture for the various treatments measured at different time intervals is shown in graphic form in Figure 3. The general levels of available soil moisture for the different treatments were as follows: 2 atmospheres—5 atmospheres—9 atmospheres—check. The moisture content of the check or non-irrigated treatment was below or near wilting point during much of the growing season. The bar graphs at the base of the chart indicate the rainfall and irrigation applications.

The average yield obtained at each moisture level and the yield for the different nitrogen levels at each of the moisture levels are shown in graphic form in Figure 3. The total acre-inches of water received by the different treatments is also shown.

SOIL MOISTURE MEASUREMENT FOR TIMING IRRIGATION

L. C. Hammond and Hugh Popenoe*

Soil-moisture measurement for regulation of irrigation is not widely practiced among growers. This is probably due to the fact that research workers have failed to prove to the farmer that soil-moisture measurement will work on his farm and that it will pay. Information of this nature is most difficult to obtain in humid regions where supplemental irrigation is practiced.

Recently, the emphasis has been toward the use of certain water-use estimates based on climatic measurements to determine the amount of available water in the soil at any time(2, 11, 19, 20). The method offers interesting possibilities as more information is obtained on all factors affecting water use rates by plants. However, both the water use or evapotranspiration method and the soil-moisture measurement method should be investigated concurrently with the objective of determining whether the methods will work for the farmer and whether they will pay.

Soil-moisture measurement methods now available have been described by several authors(6, 14, 18). In most cases, the measuring instrument indicates the moisture conditions in a very small volume of soil. For this reason, van Bavel(20) has criticized the instruments as not being practical for farmer use. On the other hand, J. E. Richards(12) and Hammond and Pritchett(7) have presented evidence that tensiometric and oven-dry methods, respectively, could be used successfully to obtain estimates of the moisture status in relatively large acreages of deep sandy soil with a minimum of sampling. This emphasizes the need for further study of the soil-moisture measurement problem from the standpoint of soil heterogeneity, desired precision of estimates, index points of measurement, evapotranspiration rates, correlation of moisture measurements and estimates with plant growth and irrigation for maximum profit. It is towards this end that this paper presents field soil-moisture measurement data obtained by two methods at two positions and two depths under citrus trees on a representative deep sandy Florida soil.

PROCEDURE

The two-acre College citrus grove on Arredondo fine sand at Gainesville was used for a soil-moisture study during the spring and summer of 1954. The sandy soil was six to seven feet in thickness over sandy clay. Physical properties of the soil profile are given in Table 1.

Mercury-manometer tensiometers of the type described by L. A. Richards(13) were used. They were installed on February 20, 1954, four per tree under seven 15-year-old Hamlin orange trees chosen at

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* Associate Soil Physicist, Agricultural Experiment Station, Gainesville; Research Assistant, College of Agriculture, Gainesville.

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random from three rows near the center of the grove. Two instrument locations were chosen: one adjacent to the tree trunk and another midway between the trunk and the edge of the tree canopy. Tensiometers were installed in 2-inch diameter holes, at depths of 12 and 24 inches, at the two locations.

TABLE 1.—PHYSICAL CHARACTERISTICS OF ARREDONDO FINE SAND UNDER HAMLIN ORANGES, COLLEGE GROVE.

Depth	Volume Weight**	Moisture Equivalent**	15-Atmosphere Percentage**	Field Capacity*
inches		%	%	%
0-6	1.38	4.95	4.11	7.51
6-12	1.52	3.35	1.80	7.71
12-18	1.50	3.21	1.66	7.61
18-24	1.52	2.71	1.49	7.12
24-30	1.56	2.41	1.25	7 03
30-36	1.49	2.24	1.27	7.55
36-42	......	2.04	1.19	6.87
42-48	1.55	1.97	1.18	6.20
48-54	......	1.91	1.04	5.08
54-60	1.55	1.74	0.93	2.35
60-66	......	......	......	......
66-72	......	......	......	......
72-78	1.62	......	......	......
78-81	1.78	......	......	......

* Based on a single profile. Field capacity is only approximated here by the moisture content of a single profile 48 hours after approximately 2.5 inches of rainfall. Water did not penetrate beyond 4½ feet.

** Based on two profiles.

One-inch by three-inch soil cores were obtained for oven-dry moisture determination on seven dates. The samples were taken at depths and positions comparable to, but not close to, the tensiometers.

The tensiometer readings on the seven oven-dry sampling dates were transformed to soil-moisture percentages by means of a calibration curve. This was determined with a suction plate (15) and an autoirrigator pot-tensiometer arrangement described by J. E. Richards (12). This curve was modified to an average field-calibration curve when it was found that the moisture estimates from the tensiometers were considerably below the oven-dry estimates. The two calibration curves are shown in Figure 1. All tensiometric soil-moisture data in this paper were taken from the field-calibration curve.

The oven-dry and the tensiometric soil-moisture data were subjected to separate analyses of variance. Besides, the variances between trees for each method, position, depth and date were calculated. These were subjected to an analysis of variance to determine their heterogeneity (1). Confidence limits were applied to the various mean soil-moisture content estimates on the basis of pooled homogeneous variances.

Rainfall data were obtained from a United States Weather Bureau Station located about 300 yards west of the grove.

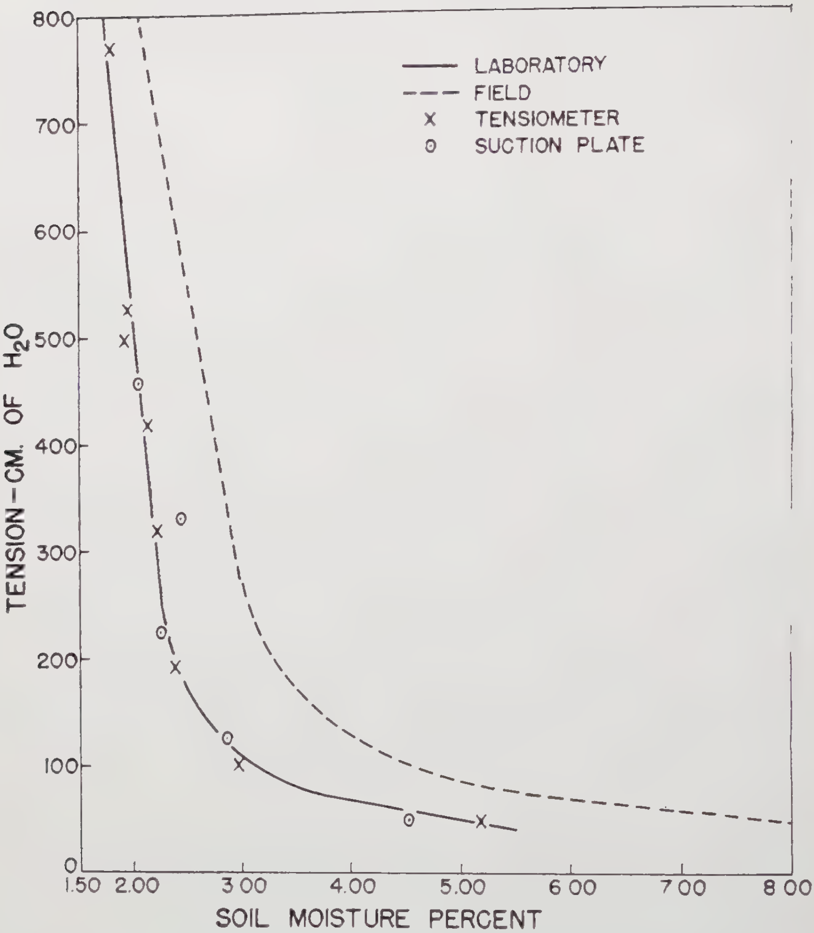

Figure 1. Soil moisture characteristic of Arredondo fine sand subsoil.

RESULTS AND DISCUSSION

The seven dates chosen for sampling the soil moisture represent the conditions which one would expect to encounter over a range from medium moisture to low moisture, including a highly heterogeneous part-wet part-dry situation. The expected moisture condition can be surmised from the rainfall data of Table 2 and the soil moisture data of Table 3. The period, March 11 to May 15 represents a soil drying cycle with intermittent small rains, producing heterogeneous soil-moisture conditions on April 15 and 24. Rainfall of fairly high intensity in late May and early June replenished the soil moisture so that the June 15 and August 18 sampling dates occurred on a second drying cycle. Both of these sampling dates came in the rainfall distribution pattern when soil-moisture con-

ditions would probably be more uniform than the conditions on the April 15 and 24 sampling dates.

TABLE 2.—Rainfall at Gainesville, Florida, During the Period January 1 to August 18, 1954.*

Date	Rainfall	Date	Rainfall	Date	Rainfall
	inches		inches		inches
January 4	0.02	April 5	0.06	July 1	0.27
11	0.27	7	0.80	2	0.30
12	0.53	10	0.37	5	0.51
17	0.17	13	0.11	6	0.02
23	0.16	17	0.12	9	0.24
31	0.01	24	0.49	10	0.80
		25	0.18	11	0.22
	1.16			17	0.03
			2.13	23	0.43
February 1	0.01			24	0.22
8	0.88	May 1	0.34	25	0.76
20	0.11	4	0.13	26	0.06
21	0.04	5	0.11	27	0.20
25	0.36	13	0.41	28	0.18
29	0.33	14	0.04		
		30	1.87		4.24
	1.73	31	0.42		
				August 4	0.02
March 1	0.33		3.32	8	0.33
3	0.03			10	0.03
7	0.16	June 4	2.76	11	0.28
14	0.02	5	0.76	14	0.01
19	0.02	17	0.18		
20	1.59	21	0.13		0.67
29	0.69				
			3.83		
	2.85				

* Official U. S. Weather Bureau Records.

The soil-moisture values in Table 3 represent the means of seven samples obtained under each of seven citrus trees. The two analyses of variance (Table 4) for the oven-dry and tensiometric methods were made on the individual sample values. First, considering the analysis of variance for the oven-dry data, the average difference in soil-moisture content at one and two feet was significant. Note in Table 3 that the oven-dry moisture content averages were higher at one foot than at two feet. This result would be expected on the basis of the rainfall distribution and intensity discussed earlier. This difference between depths depended on sampling dates but not on sampling positions.

The average difference between the two sampling positions was not significant, but this difference between positions was not constant from tree to tree and from one sampling date to another. It was, however, independent of depths. It is interesting to note in Table 3 that on April 24 the trunk position was wetter than the canopy position while the reverse was true on August 18 after extended drying. The one-half inch of rainfall immediately prior to the April 24 sample date was probably

TABLE 3.—SOIL-MOISTURE CONTENT OF ARREDONDO FINE SAND UNDER HAMLIN ORANGES DETERMINED TENSIOMETRICALLY AND BY OVEN-DRYING AT TWO DEPTHS AND TWO POSITIONS ON SEVEN DATES IN 1954.

Depth	Position	Method	Soil Moisture Content							
			Mar. 1	Mar. 18	April 15	April 24	May 15	June 15	Aug. 18	Average
feet			%	%	%	%	%	%	%	%
1	Canopy	Oven-dry	4.48	3.93	5.87	4.51	2.69	3.87	2.45	3.97
		Tensiometer	4.10	3.72	4.69	3.15	2.26	3.33	2.11	3.34
	Trunk	Oven-dry	5.08	3.44	4.97	5.48	2.97	3.15	2.19	3.90
		Tensiometer	4.69	3.09	4.50	5.30	2.92	2.90	2.15	3.65
	Average	Oven-dry	4.78	3.69	5.42	5.00	2.83	3.51	2.32	3.94
		Tensiometer	4.40	3.41	4.60	4.73	2.59	3.12	2.13	3.50
2	Canopy	Oven-dry	3.83	3.16	3.73	3.35	2.36	3.77	2.10	3.19
		Tensiometer	4.53	3.66	5.04	3.60	2.26	5.02	2.15	3.75
	Trunk	Oven-dry	4.20	3.81	4.55	4.25	2.63	2.92	1.97	3.48
		Tensiometer	4.89	4.01	5.51	5.45	3.45	4.15	2.19	4.24
	Average	Oven-dry	4.02	3.49	4.14	3.80	2.50	3.35	2.04	3.34
		Tensiometer	4.71	3.84	5.28	4.03	2.86	4.59	2.17	4.00
Average		Oven-dry	4.40	3.59	4.78	4.40	2.66	3.43	2.18	3.63
		Tensiometer	4.55	3.62	4.94	4.38	2.72	3.85	2.15	3.74

channeled to the tree trunk by the limbs of the tree. Hammond [1] found that in comparison to the actual rainfall the effective rainfall was three to four times higher immediately around the trunk and less than one-half to slightly higher at various points under the tree canopy.

The average differences between trees were not significant, but the pattern of tree differences changed with sampling dates. This result is not surprising in view of the high variability in soil moisture which can be found under a single tree(7, 8).

The soil-moisture values transformed from tensiometer readings were found to differ significantly with the same variables as the oven-dry method. but in addition trees and certain interactions were found to be significant. The result was largely due to one fundamental difference in the two methods of determining soil moisture. In the oven-dry method, a new soil sample from a slightly different location was obtained with each sampling. The tensiometers remained in place over the season and measured the moisture content of the same soil sample every sample date. Thus. if on one sample date the soil adjacent to a tensiometer had been wetter than average. it would probably tend to be wetter than average on subsequent sampling dates. The accumulative effect of tensiometers tending to respond alike over several sampling dates would help to make tree totals differ significantly. J. E. Richards(12) has shown this type of tensiometer response. Nevertheless, on the basis of the comparative oven-dry and tensiometric data in Table 3. this characteristic of tensiometric measurements did not appear to be a disadvantage.

TABLE 4.—Analysis of Variance of Oven-Dry and Tensiometrically-Determined Soil Moisture Under Hamlin Oranges on Arredondo Fine Sand.

Source of Variation	Degrees of Freedom	Mean Square	
		Oven-Dry†	Tensiometer‡
Positions	1	0.55	7.80
Depths	1	17.81*	12.28*
Positions x Depths	1	1.60	0.35
Trees	6	2.33	5.19***
Trees x Positions	6	1.46*	5 68***
Trees x Depths	6	0 45	1.80**
Trees x Depths x Positions	6	0.71	3.73***
Dates	6	26.04***	28.41***
Dates x Positions	6	2.05**	5.45***
Dates x Depths	6	1.60*	1.54**
Dates x Depths x Positions	6	1.00	10.74***
Dates x Trees	36	1.66***	0.95**
Remainder of Interactions	108	0.62	0.44

† For the oven-dry method, periods and trees were considered random and positions and depth fixed.

‡ For the tensiometer method, trees were considered random and periods, positions and depths fixed.

* Significant at the 5% level.

** Significant at the 1% level.

*** Significant at the 0.1% level.

[1] Hammond, L. C. Unpublished data, Florida Agricultural Experiment Station.

TABLE 5.—VARIANCES WITHIN SEVEN SOIL MOISTURE SAMPLES TAKEN UNDER EACH OF SEVEN TREES AT TWO DEPTHS AND POSITIONS AND USING TWO METHODS OF MEASUREMENT.

Depth	Position	Method	Variance							
			Mar. 11	Mar. 18	April 15	April 24	May 15	June 15	Aug. 18	Average
feet										
1	Canopy	Oven-dry	0.5149	0 7076	2.4463	3.0785	0.1719	0.1901	0.1222	1.0331
		Tensiometer	0.5546	0.3866	0.6160	0.3235	0.0925	0.3762	0.0347	0.3406
	Trunk	Oven-dry	0.7018	0.2483	0 5029	6.4593	0.4925	0.1447	0 0314	1.2258
		Tensiometer	0.8642	0.1407	0.6893	6.8764	0.6145	0.6161	0.0039	1.40077
2	Canopy	Oven-dry	0.1145	0.2234	1.8554	0 8986	0.0668	0.1159	0.0225	0.4710
		Tensiometer	1.3296	0.5162	4.1940	3.7409	0.0602	0.1962	0.0034	1.4344
	Trunk	Oven-dry	0.3385	0.1895	1.9540	2 0355	0.4478	0.2466	0.0159	0.7468
		Tensiometer	0.5157	0 1375	0.7184	8.0340	1.4029	0.2880	0.0170	1.5876
Average		Oven-dry	0.4174	0.3422	1.6897	3.1180	0.2948	0.1743	0.0480	3.4768
		Tensiometer	0 8160	0.2952	1.5544	4 7437	0.5425	0.3691	0.0148	4.7633

Another important factor in the significance of the tensiometer results is apparent from the data in Table 3. The tensiometers tended to overestimate the soil-moisture content at the two-foot depth and to underestimate it at the one-foot depth. However, the over-all tensiometric and oven-dry estimates do not differ significantly. This indicates that the date averages of the two moisture estimates were adequate for adjusting the laboratory curve to a field curve as far as the over-all average was concerned. However, the data indicate that no single field curve could be used for the two depths.

The difference in the laboratory and field calibration curves and the difference in the tensiometer-soil moisture relationship with depth may reflect the presence and relative activity of roots adjacent to the tensiometer cup. On the other hand, temperature differences at the two depths might also contribute to the calibration differences(5). Koo(10) used barley plants to obtain a laboratory calibration curve, but he also found the same discrepancy between field and laboratory curves for the 18-inch depth at tensions greater than 150 cm. of water.

The variances associated with the means of Table 3 are presented in Table 5. These variances are seen to be quite heterogeneous, especially between sampling dates. The heterogeneity is clearly evident in the analysis of variance of the log of variances from Table 5 which is presented in Table 6. In addition to significant date differences, the interactions—"methods x depths" and "dates x positions"—were significant. Examination of the data in Table 5 reveals how this occurs. The oven-dry method was least variable at two feet while the tensiometric method was least variable at one foot. However, this difference does not appear to be of any great consequence since it can be attributed mostly to the highly variable conditions on April 15 and 24.

TABLE 6.—Analysis of Variance of the Log of Variances within Seven Oven-Dry and Seven Tensiometric Soil Moisture Samples Collected at Two Positions and Depths on Seven Dates.

Source of Variation	Degrees of Freedom	Mean Square
Positions	1	0.1530
Depths	1	0.0875
Positions x Depths	1	0.0971
Methods	1	0.0000
Methods x Positions	1	0.0381
Methods x Depths	1	0.4426*
Methods x Positions x Depths	1	0.1595
Dates	6	3.7915***
Dates x Positions	6	0.4578**
Dates x Depths	6	0.1017
Dates x Methods	6	0.1898
Dates x Positions x Depths	6	0.1125
Dates x Methods x Positions	6	0.0639
Dates x Methods x Depths	6	0.1479
Dates x Methods x Positions x Depths	6	0.0420

* Significant at the 5% level.
** Significant at the 1% level.
*** Significant at the 0.1% level.

The heterogeneity of these variances violates one of the fundamental assumptions underlying the analysis of variance. Therefore, the analyses given in Table 4 could probably be improved by grouping wet and dry periods and eliminating the highly heterogeneous part-wet part-dry periods. However, for the present purpose this does not appear to be necessary, since Cochran(3) states that the effects of heterogeneous errors is largely in the loss of efficiency in the estimates of treatment effects and that the validity of the F-test is probably least affected. It is possible, however, to use tables prepared by David(4) to determine quickly which variances are homogeneous and can therefore be pooled to get a standard error for the means of Table 3. The results from the above pooling procedure are given in Table 7. The variances for some means could not be readily pooled, so the standard errors were not calculated. The low variances for tensiometers on August 18 give a somewhat false picture, due to the fact that all tensiometers were at or approaching the maximum tension which they are capable of indicating(16).

TABLE 7.—STANDARD ERRORS FOR THE SOIL MOISTURE MEANS OF TABLE 3.*

Means to Which Applicable **	Degrees of Freedom	Standard Error
All means on March 11, 18, and June 15	144	0.2398
All means on April 15	48	0.4814
Oven-dry means on April 24	24	0 6675
Oven-dry means on May 15	24	0.2053
Oven-dry means on August 18	24	0.0828
Tensiometer means on August 18	24	0.0459

* Where the variances were too heterogeneous no standard errors were calculated. They can be calculated for each mean from the variances in Table 5.

** Means under "average" columns of Table 3 not included.

The precision with which the means of seven determinations were estimated varies from slightly less than 10 percent of the mean on a dry sampling date to more than 20 percent of the mean on wet and part-wet part-dry dates. Thus the number of samples required for a given precision will depend largely upon the soil-moisture condition at the time the measurement is taken.

The next step, as far as soil-moisture measurement for irrigation timing is concerned, is to correlate a soil-moisture content or soil-moisture tension determination with maximum profit from irrigation. Taylor(17) has shown that plant growth can be correlated with a depth-integrated soil-moisture stress, but this method requires too many measurements. The only practical alternative is to measure the soil-moisture status at one or two maximum profit correlative points in the soil volume permeated by plant roots.

The present data, though incomplete in relation to plant growth, are relevant to the problem of soil-moisture measurement for timing irrigation. They show that the oven-dry and tensiometric methods can be used to measure soil moisture even when small soil samples are involved. The variances of the two methods are about the same especially at

moisture levels which the grower would be interested in measuring. However, due to the hyperbolic nature of the soil-moisture tension—moisture content curve, the variance of tensiometer readings themselves would most always be higher than the variance of the soil-moisture percentages. This fact has led to confusion in the minds of some regarding the usefulness of the tensiometer even though various workers(6, 9, 14) have emphasized the fact that tensiometers operate satisfactorily over most of the available soil-moisture range of sandy soils.

In practice, the timing of irrigation would be based on a certain soil-moisture tension, so that there would be no need for calibration curves. The transformations of tensions to moisture in this paper were made primarily for the purpose of comparative statistical analyses of the two methods of soil-moisture measurement.

The choice of an "irrigation time" moisture content or stress level from variable data presents a real problem. On a uniform drying cycle, an average moisture content and a median tensiometer reading would probably be suitable(12). However, in extreme cases of soil-moisture variability—such as was the case in the present study on April 15 and 24—both of these reference levels would probably be supplemented by other considerations in deciding whether to irrigate. It seems logical that a precise estimate of the mean on these dates would not only be impractical, but valueless. In fact, these data show that as the soil dries to moisture levels where irrigation might normally be used, the variance decreases. Thus at times when more precise measurements might be desired, the precision increases due to a decreasing variance.

The number of soil-moisture samples or tensiometers required to time irrigation in a large citrus grove on deep sandy soil may be no more than a half dozen. This depends upon the soil heterogeneity. In macro-uniform soil areas such as the one in this study and the areas sampled by J. E. Richard(12) and Hammond and Pritchett(7) the samples can be taken in groups or clusters for convenience. Also, the numbers of samples does not increase with the size of such areas as erroneously concluded by Koo(10).

The choice of position and depth of sampling cannot be definitely determined from this study without data correlating soil moisture and plant growth. However, for tensiometers, a depth of two feet would have the advantage of less rapid fluctuation to high readings with consequent increased frequency of servicing.

SUMMARY

Soil-moisture data from a deep, well-drained sandy soil under citrus trees were collected on seven dates, using the oven-drying and tensiometric methods. The detailed study showed that tensiometers were as useful as oven-drying for estimating the soil-moisture content over most of the available range. The variance of sample means for the two methods were approximately the same at soil-moisture conditions where precise measurement for irrigation timing would normally be desired. However, the variances of both methods decreased with a uniform decrease in the soil-moisture content. Thus, different soil-moisture conditions on the seven dates produced a significant difference in the variances of means for the different dates.

The application of these data to some of the problems of soil-moisture measurement for irrigation timing was discussed.

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WATER REQUIREMENTS OF FIELD CROPS IN FLORIDA AS INFLUENCED BY CLIMATE

D. E. McCloud*

Irrigation engineers in western United States, for many years, have used the crop-water requirement concept as a basis for scheduling water applications. They have associated, in a general way, water requirements of crops with climate. During the last decade, considerable interest in supplemental irrigation has developed in humid regions. Thornthwaite(1) in 1948 presented a formula which is being used to compute the water requirement of crops. Penman(2) at about the same time developed a formula, based upon energy relations, for use in determining crop-water use.

Crop-Water Requirements

Early in 1952, crop-water requirement studies were begun in Florida. A comparison of measured vs. computed water requirements for one year were reported by McCloud and Dunavin(3) in 1954. A similar comparison for two years is shown in Figure 1. Measured water-use was determined with a modified Thornthwaite type evapotranspirometer. Calculated water-use rates were computed according to the formulas of Blaney and Criddle(4), Tabor(5) and Thornthwaite(1).

At Gainesville, water-use was underestimated by all the formulas when the mean temperature was above 70°F. Blaney and Criddle's unadjusted linear formula was only in accord with measured values at temperatures of around 65°F. At lower temperatures predicted values are high, and at temperatures above the mid-sixties computed values are low compared to measured values. Tabor's exponential relationship gives a better fit, but does not increase fast enough at high temperatures. Thornthwaite's unadjusted curve more closely parallels the measured water-use in the range of 50-75°F., but fails to provide for the sharp increase above 75°F. This rapid increase may be brought about, in part, by advective heat transfer in the tanks. This factor can lead to grossly exaggerated measured water-use rates.

In an endeavor to mathematically express the relationship between measured water-use at Gainesville and mean temperature, an empirical formula was developed. Then an exponential curve was fitted, by least squares, to the data. The formula:

$$\text{Potential Daily Water-Use} = KW^{T-32}$$

was found to fit the data best when $K = .01$, $W = 1.07$, and $T =$ mean temperature in °F. It is important to note that this formula provides for no upper limit to the rate of crop-water use. An upper limit does exist and it is only for simplification that no upper limit factor is added to the formula. Extrapolation beyond the range of temperatures occur-

* Associate Agronomist, Florida Agricultural Experiment Station.

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ring in Figure 1 should not be attempted. The measured use-rate increased rapidly with high temperatures (Figure 1). Even within the range of measured temperature in Figure 1, temperatures in the high region (around 80°F.) produced water-use rates which were slightly higher than expected on an available energy basis. Work now in progress indicates that advective energy transfer from drier areas outside the tanks is at least partially responsible for these exaggerated water-use rates. This is an important consideration in evapotranspiration studies.

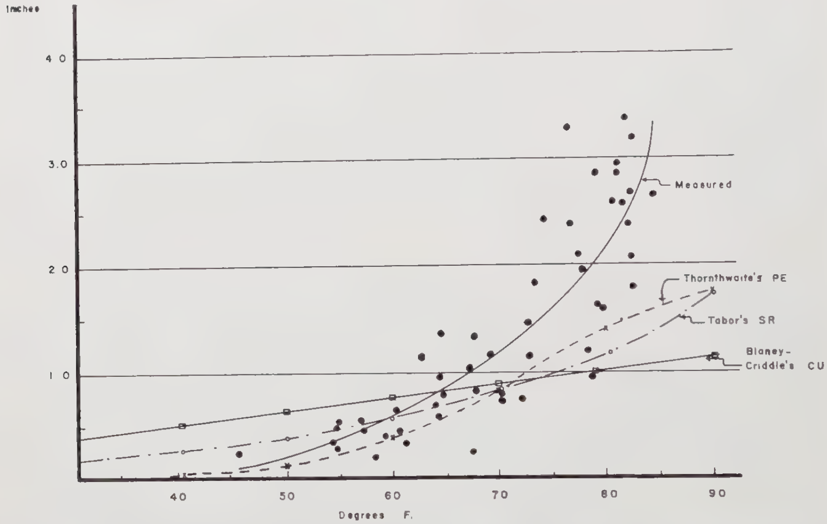

Figure 1. Relationship between computed and measured potential evapotranspiration of bahiagrass. Gainesville, Florida, 1952-54.

Over most of the temperature range, measured values are within the limits of available energy. The above formula, then, was used to compute a predicted weekly water-use value. A high correlation was found between those predicted and the measured water-use rates.[1]

Agrohydrologic Balance

This water-use rate, or evapotranspiration of plants, is an important aspect of the crop-water balance. It has been the missing link in the water cycle. Assuming that it is a reasonable estimate of the crop-water use rate, by using a simple bookkeeping procedure, water balance can be computed from precipitation, evapotranspiration, run-off, and soil storage data (Figure 2).

First the plant-soil water storage reservoir must be determined. This is a function of the plant's rooting depth, and the available water-holding capacity of the soil. Thus, for a particular plant-soil combination there is a maximum water storage. Precipitation replenishes this plant water supply while evapotranspiration depletes it. After water storage reaches

[1] For the first year's data the correlation coefficient of $r = 0.91^{**}$ (significant at the 1% level of probability). Thus mean temperature accounted for over 80 percent of the variations in water-use.

its maximum value. additional precipitation is lost through percolation. Runoff is of course first subtracted from precipitation. It is interesting to note that even if the computed rate of evapotranspiration is in error by some considerable amount. the fluctuation of plant-soil water storage between fixed limits provides an auto-correction. Thus the resultant crop-water balance determinations are not seriously affected.

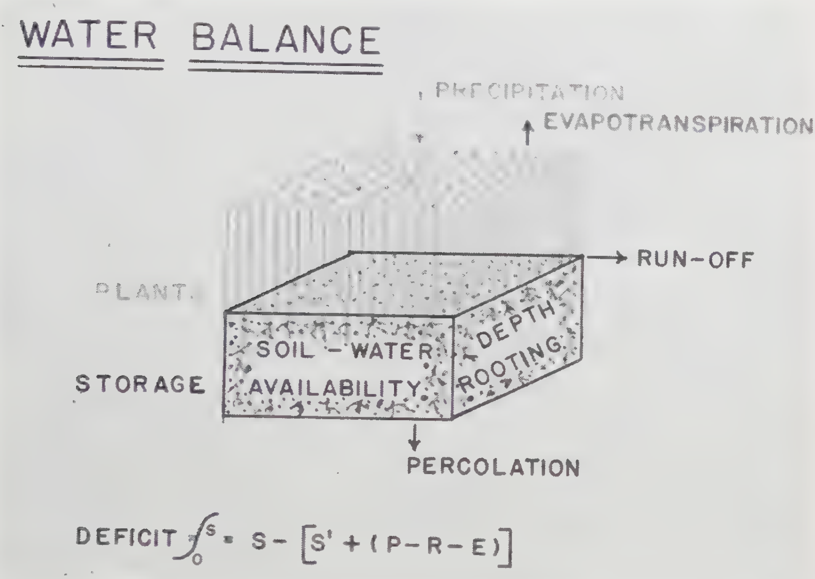

Figure 2. Diagramatic water balance.

Daily crop-water balance can then be calculated from meteorological records of precipitation and temperature. Agrohydrologic balance can be contrasted in unusually wet or dry years. Or comparisons can be made between crop-water balance when specific combinations of different textured soils and different crops are involved. Such preliminary calculations were made to illustrate the crop-water balance in a wet year at Gainesville, Florida (Figure 3). The rainfall of over 73 inches was the largest yearly rainfall on record at Gainesville. Evapotranspiration, computed from mean daily temperatures and the preceding formula, amounted to over 70 inches for the year. With a two-inch plant-soil storage, the crop-water deficit amounted to almost 18 inches even in this record wet year. A percolate of 20 inches occurred.

Conversely, the year of 1954 was one of the driest on record with only 36 inches of rainfall. Since it was also slightly warmer the year's evapotranspiration was a little over 72 inches. A crop-water deficit over twice as large as for 1953 occurred. Percolation, as would be expected, decreased to about four inches (Figure 4).

Considering another plant-soil combination, having a four-inch storage reservoir changes the deficit and percolate values (Figure 5). For the wet year of 1953, with a four-inch storage, the deficit amounts to about

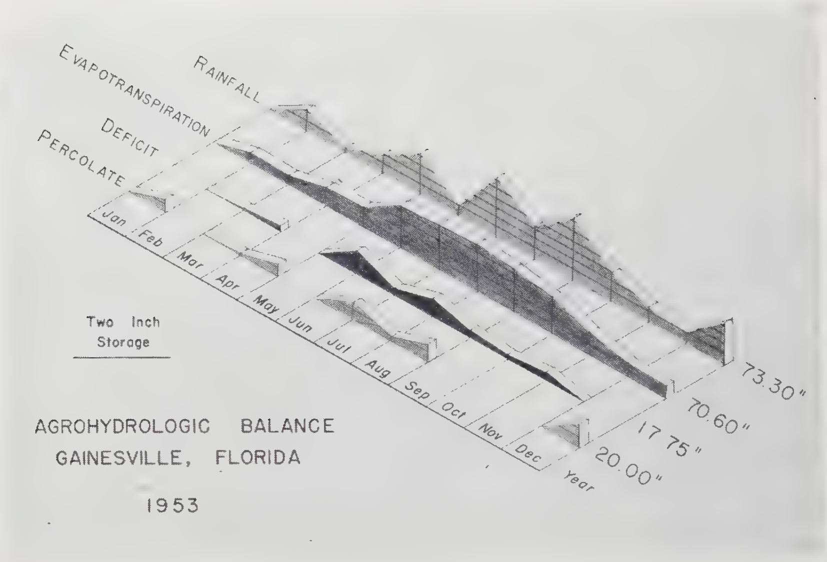

Figure 3. Agrohydrologic balance with two inch storage. Gainesville. Florida. 1953.

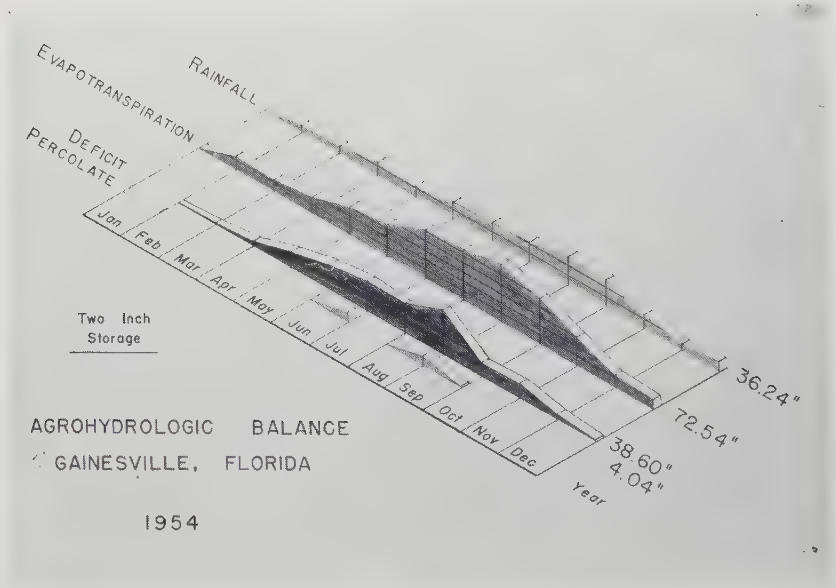

Figure 4. Agrohydrologic balance with two inch storage. Gainesville, Florida. 1954.

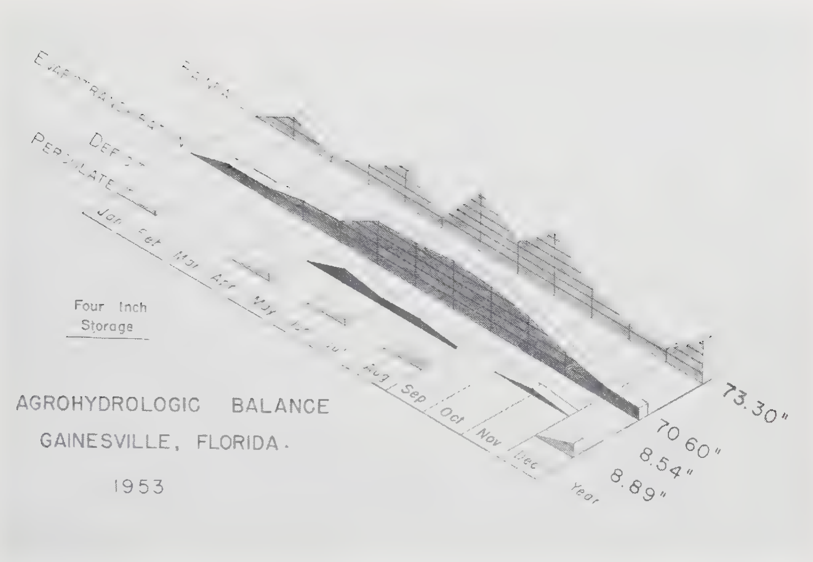

Figure 5. Agrohydrologic balance with four inch storage. Gainesville, Florida. 1953.

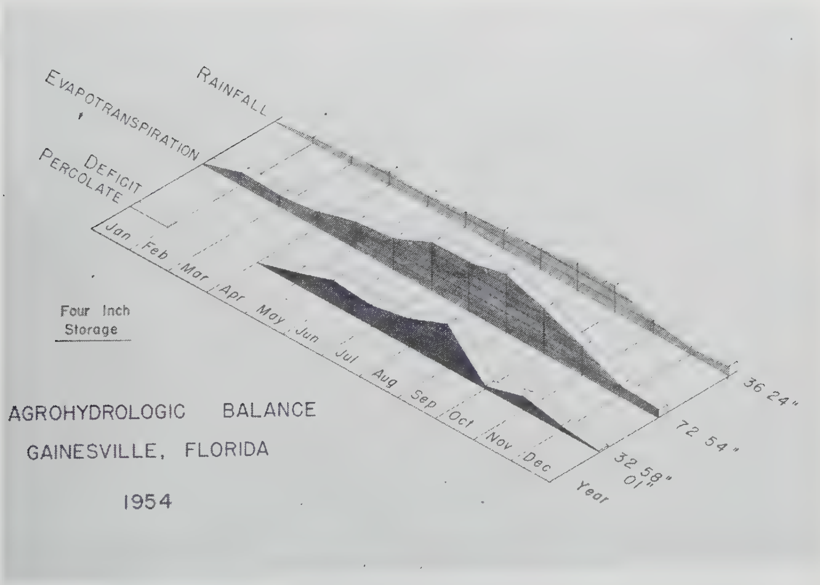

Figure 6. Agrohydrologic balance with four inch storage. Gainesville, Florida. 1954.

eight inches—just half that for the two-inch storage. Percolation is reduced even more sharply, less than nine for the four-inch storage, compared to twenty inches for the two-inch storage level in 1953. In the 1954 dry year, the evapotranspiration deficit was changed very little by increasing the crop-water storage from two to four inches (Figures 4 and 6). Percolation, as expected, decreased from four inches to almost zero by the change in storage level.

These agrohydrologic balance parameters are of primary concern to agriculturists. Evapotranspiration deficit is of use to engineers in determining irrigation requirements for any particular crop season. Percolation value furnishes an estimate of fertilizer leaching tendency. Water deficit or percolation, for months or seasons, can be compared; or different years may be constrasted. These comparisons furnish a much more valid basis for assessing the crop-water balance than the more commonly used one—simple rainfall.

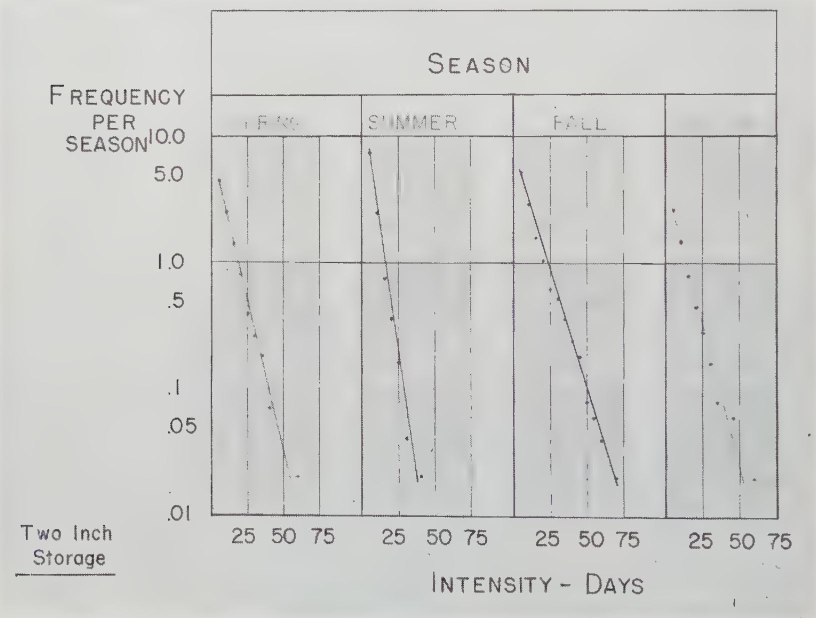

Figure 7. Drouth frequency and intensity with a two inch storage. Gainesville, Florida. 1904-53.

Drouth Frequency and Intensity

A second important utilization of the agrohydrologic balance concept is its application to long-time climatological records. Using this approach probabilities of occurrence of any crop-water balance component can be computed. For example, drouth frequency can be determined for a given crop-water storage level. Drouth, in this case, is defined as any day when the crop-water storage is depleted—a much more factual approach than a consideration of rainfall alone. In addition, the intensity and

successive length in days of the expected drouth can be ascertained. Thus a drouth characterization, both with respect to frequency and intensity, can be determined using long-time climatological records.

From Figure 7, the expectancy of any duration drouth can be determined for each season of the year. The expectancies shown are based on the season in which a given drouth begins. It is of interest to note that the semi-logarithmic transformation effects a straight line relationship. At Gainesville, short duration drouths—up to five days—are most frequent during the summer and least frequent in winter. The fall season is most likely to have drouths of long duration—one of seventy days would be expected once every fifty years with a two-inch storage level.

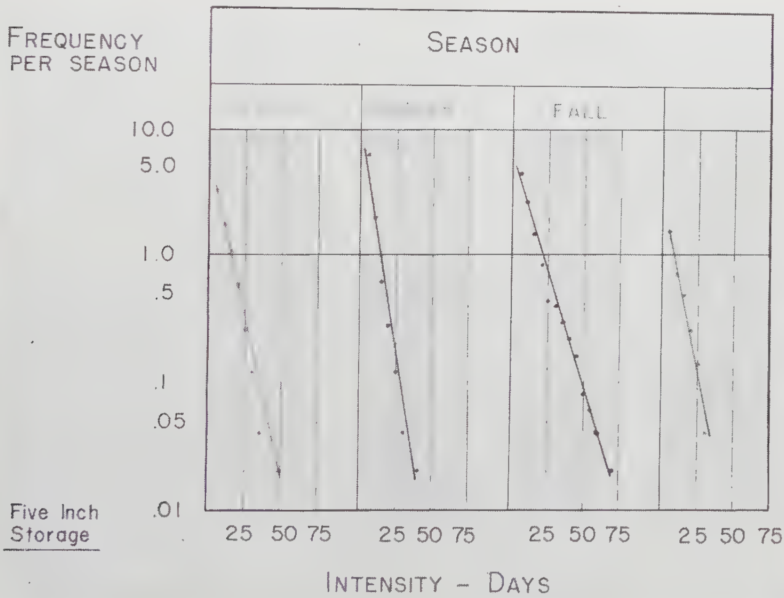

Figure 8. Drouth frequency and instensity with a five inch storage. Gainesville, Florida. 1904-53.

Figure 8 gives the analysis based on a five-inch, instead of two-inch storage level. The fall probabilities remain almost exactly the same irrespective of the storage level chosen. Thus in the fall deep rooted crops, for example, would suffer from a lack of water at about the same time as shallow rooted ones. Distribution of rainfall is more important than water storage level in the fall. Similarly, drouth expectancies for spring and summer do not change markedly for the two storage levels. Again storage level is relatively unimportant. Winter drouth probabilities, conversely, are altered as the storage level changes—longer duration drouths occurring more frequently with the smaller storage level. This pattern would be expected with heavy late fall rains to replenish the large storage reservoirs.

Summary and Conclusions

Crop-water use rates have been measured and an empirical formula developed for predicting them from daily mean temperature. Values from this empirical formula show fair agreement with values from other well-known formulas in the lower temperature ranges —below 70°F. At higher temperatures, a larger discrepancy exists. Under certain conditions the exaggerated water-use rate may be caused by advective energy transfer from the area surrounding the tanks—an important factor to delineate in crop-water use studies.

Using daily precipitation, evapotranspiration, and a given water storage level, agrohydrologic balance can be computed. Crop water deficits, useful to the irrigation engineer, can be computed. Water lost by percolation, a measure of leaching potential, likewise can be calculated. Thus a much better measure of crop-water balance results.

A further extension of the concept, based on long-time climatological records, provides the expected frequency and intensity of drouths. This is a much better characterization of drouth with respect to crop plants than is presently available.

The water requirements of field crops in Florida are influenced by climate, but the specific climatic elements can now be separated, a feature not heretofore possible.

ACKNOWLEDGMENTS

Climatological data was furnished by the United States Weather Bureau, and computations were made by the University of Florida Statistical Laboratory.

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IRRIGATION OF VEGETABLES IN FLORIDA

F. S. JAMISON*

Vegetables are an important group of crops in the economy of the state. Last season, July 1, 1954, to July 1, 1955, the F.O.B. value was approximately $192,000,000. This is approximately 30% of the value of the agricultural income of the state.

It is a reasonably safe estimate that more than one-half of the vegetables grown receive irrigation. Indeed, the vegetable producing areas have largely been determined by the availability of an adequate supply of water that could be used at a relatively low cost. Thus the artesian water belts of the state have been well utilized by vegetable growers. Other important vegetable producing areas depend on surface, lake, or river water for irrigation.

Irrigation of vegetables in Florida has been done by a number of methods depending not only on the water supply available but also on the prevalent soil type. In general and in lieu of a more accurate description, we could say that water is applied to vegetables from the top, the bottom, and sideways. Water for irrigation is usually distributed through the field by canals and lateral ditches, although underground pipe may be substituted for open ditches. From these laterals it may be distributed through the remainder of the field by: (1) seepage across a layer of impervious soil, as in the Hasting potato area; (2) a system of underground moles, as in the muck and peat areas; (3) through underground tile laid on top of an impervious soil, as in the Sanford area; (4) raising the water table as in the lower east coast; (5) surface applications between the plant rows; and (6) sprinkler irrigation. While the use of the sprinkler type of irrigation may be relatively new for farm crops and pastures, its use is not new in vegetable production. A trip through the Bartow, Sumter County, or McIntosh-Gainesville area will reveal many old installations of overhead sprinkler equipment. This type equipment was expensive to install and maintain and water was applied at a slow rate. The development of portable, easily assembled and relatively economical systems, applying water in a relatively short time, has again renewed interest in sprinkler irrigation for vegetables.

At Gainesville sprinkler irrigation was tried with six different vegetables over a six-year period. During this period of time five crops of cabbage, four crops of sweet corn, two crops of beans, and one each of onions, tomatoes, and cucumbers were grown. Of these fourteen crops with six vegetables, all but three showed a very definite increased yield with irrigation. This study was conducted on Arredondo soil. Many rates and times of irrigation were used during the trials with probably one-half inch every six days being satisfactory except with sweet corn, which showed maximum increases with larger amounts of water.

Yields are important and one typical example will illustrate what might be expected with irrigation in a dry spring. Sweet corn was planted

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* Horticulturist, Florida Agricultural Experiment Station, Gainesville, Florida.

at a number of spacings and various amounts of water applied. The yield in number and weight of ears is given for the various treatments in Table 1. At the closest "in-the-row" spacing, 6 inches, the weight and number of ears increased as the amount of water applied increased. With no irrigation, 10,708 ears an acre, weighing 4,009 pounds were produced; with frequent watering (largest quantity of water) the number of ears increased to 28,344, weighing 13,086 pounds.

TABLE I.—Number and Weight of Ears of Golden Security Sweet Corn Produced per Acre When Grown at Varying Spacing and Irrigation Treatments.*

Irrigation Treatment	Spacing in Row of Plants							
	6 Inch		12 Inch		18 Inch		24 Inch	
	No. Ears	Wt. Ears	No. Ears	Wt. Ears	No. Ears	Wt. Ears	No. Ears	Wt. Ears
No irrigation	10,708	4,029	12,342	5,003	12,372	5,789	10,890	5,242
Occasional ..	16,909	6,706	16,607	7,750	14,459	7,623	13,340	7,072
Medium	24,018	10,049	22,415	11,253	16,486	9,335	14,671	8,264
Frequent ...	28,344	13,086	25,289	13,890	19,360	11,232	16,516	9,398

* Adapted from Irrigation and Other Cultural Studies with Cabbage, Sweet Corn, Snap Beans, Onions, Tomatoes, and Cucumbers. Fla. Agr. Expt. Sta. Bul. 495.

At the widest "in-row" spacing, 24 inches, 10,890 ears weighing 5,242 pounds were produced when no water was applied. The yield increased to 16,516 ears, weighing 9,384 pounds where the largest amount of water was applied. As can be seen, when no irrigation was applied, the largest number and weight of ears was produced at a wider spacing, but with the application of large amounts of water the close spacing outyielded the wide spacing approximately 70% in number of ears and 40% in weight. This illustrates the need to consider cultural treatments when studying irrigation.

Another outstanding example of the effect of irrigation on yield was a spring crop of green beans. Where no irrigation was applied the yield was 24 bushels an acre; with light applications of water, 197 bushels; 230 for heavy applications and 291 where the heavy rate of watering was applied in split applications. As the yield of beans increased the quality also increased. Quality is of course, of utmost importance with vegetables.

This effect on quality was more easily evaluated with a crop of cucumbers. With no irrigation the yield (as shown in Table 2) was 283 bushels an acre with approximately 40% being U. S. No. 1 grade or better; when medium amounts of water were applied the total yield increased to 437 bushels with 55% U. S. No. 1 or better. With the heaviest amount of water the total yield was lower than with the medium quantity. This latter trend was noted with several crops and is probably due to the leaching of certain plant nutrients from the root zones when large amounts of water are applied at any one irrigation.

While no statistical counts were made, there was important difference in aphid infestation and the occurrence of several important diseases

on a number of crops produced. For instance, on one crop of cabbage there was severe infestation on non-irrigated and none on cabbage receiving frequent irrigation.

TABLE II.—EFFECTS OF VARYING AMOUNTS OF IRRIGATION ON THE YIELD AND MARKET GRADE OF CUCUMBERS.*

Irrigation Treatment	Bushels per Acre	
	U. S. No. 1's	Total
No Irrigation	116	283
Light	140	325
Medium	243	437
Heavy	229	394

* Adapted from Irrigation and Other Cultural Studies with Cabbage, Sweet Corn, Snap Beans, Onions, Tomatoes, and Cucumbers. Fla. Agr. Expt. Sta. Bul. 495.

Another important use of irrigation in Florida is cold or heat protection. Work at Plantation Laboratory, Fort Lauderdale, showed that maximum yields of beans was secured with a 21-inch water table; as the water table was raised or lowered from this level, yields decreased. The effect of these varying depths of water table on temperature was observed. When the air temperature decreased from 84°F. to 34°F., the temperature change at a six-inch soil depth was recorded for the plots having the water table at varying depths. A twelve-inch water table showed a drop in temperature at the six-inch depth of from 68°F. to 54°F.; at the eighteen-inch, from 74° to 52°F.; and at twenty-four inches 76° to 50°F. The higher final temperatures are of value on cold nights. However, the effects of varying depth of water tables on the initial temperature are in many instances of equal or more importance. High soil temperatures are a detriment in early fall planting.

There are many other areas of investigation in the uses of irrigation on which research has indicated promising results. The salt content of water used for irrigation is relatively high in certain areas. These salts affect the growth and yields of plants. In the Fort Myers area Geraldson of the Gulf Coast Experiment Station has shown that when the total salts in the soil dropped from 2,710 PPM to 1060 PPM, the yield of potatoes was doubled. It would seem that the quality of water as well as quantity needs to be evaluated.

Irrigation of vegetables is well established and widely used in Florida. Many methods of applying water are used, the more common being seepage from ditches and controlling the height of the water table. The use of sprinkler irrigation is increasing in importance. Use of this type of irrigation at Gainesville on fourteen crops of six vegetables resulted in increased yields and improved quality in most instances. Other research has indicated the effects of irrigation on soil temperatures and salt content of the soil. Preliminary observation on insects and disease infestation suggest the desirability for additional observations.

IRRIGATION OF PERMANENT PASTURE FOR LACTATING DAIRY CATTLE

J. Mostella Myers and Sidney P. Marshall*

In the spring of 1952 the Agricultural Engineering and Dairy Science Departments initiated a three-year research project at the Dairy Research Unit, Hague, Florida, on the irrigation of pangola - white clover pasture for lactating dairy cows. Four pasture plots, established on a soil principally Scranton loamy fine sand, were used in 1952. They were redivided into eight pastures in 1953. Irrigation water was applied to one-half of the pasture plots, with the remaining comparable pastures used as non-irrigated controls.

A shallow well supplied irrigation water which was distributed on the pastures by a portable overhead sprinkler irrigation system at a rate of approximately one-half inch per hour. The interval between irrigations was determined by the time required for about 75 percent of the available moisture in the top six inch layer of soil to be removed from the soil. Soil moisture determinations were made by oven-drying samples taken mechanically from the soil at depths from 0 to 18 inches. The percentage of soil moisture at field capacity, soil-moisture percentage at wilting and specific gravity by depths are shown in Table 1.

Each irrigation application was of sufficient size to bring the moisture level in the top 18 inches of soil to field capacity. The interval between applications was generally four to seven days when rainfall was not sufficient to meet the moisture requirement of the pasture and the size of applications varied from 0.8 inch to 1.2 inches. The shorter intervals between irrigations occurred and the larger applications were made during June, July and August of each year. A summary of the rainfall and of irrigation water applied is shown in Table 2.

Two tons of ground limestone were applied per acre prior to establishing the pasture in 1950 and 2,400 pounds were spread per acre in the fall of 1954. Superphosphate was applied annually in the fall; split applications of murate of potash were made in the fall, winter and spring, and each pasture was top-dressed with nitrogen during the spring, summer and fall. A summary of the phosphorus, potash and nitrogen applied for each pasture season is shown in Table 3.

It is estimated that more than 95 percent of the forage produced on the pastures was consumed by the grazing cows. Pastures were mowed when necessary to control weeds and to keep the forage in a uniform vegetative condition. Cattle droppings were spread to minimize clumping of forage.

Separate groups of cows were used to graze the irrigated and non-irrigated pasture plots. Grazing was begun when sufficient pasturage had accumulated in the late winter and continued until the growth became

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* Associate Agricultural Engineer, and Associate Dairy Husbandman, respectively, Fla. Agr. Expt. Stations, Gainesville.

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TABLE 1.—PERCENTAGE OF SOIL MOISTURE AT FIELD CAPACITY, SOIL MOISTURE PERCENTAGE AT WILTING AND SPECIFIC GRAVITY BY DEPTHS.

Depth in Inches	Soil Moisture Percentage		Specific Gravity
	Field Capacity	Wilting Point	
0 - 1	14	4.0	1.52
2 - 6	12	4.2	1.52
7 - 11	10	3.8	1.54
14 - 18	9	3.4	1.56

TABLE 2.—RAINFALL AND IRRIGATION SUMMARY, 1953, 1954 AND 1955.

Grazing Period†	Number Irrigation Applications	Irrigation, Inches	Rainfall, Inches	Total Rainfall and Irrigation	Expected Rainfall, Inches*
1952 clover**	6	7.20	3 60	10.80	5.07
1952 grass	14	15.54	21.00	36.54	29.30
1953 clover	23	18.47	15.78	34.25	20 50
1953 grass	5	4.82	33.76	38.58	29.30
1954 clover	7	6.49	20.81	27.30	20.50
1954 grass	11	12.76	29.24	42.00	29.30

* Average rainfall at Gainesville 1903 - 1955.

** 1952 rainfall and irrigation data are for the period April 18 - May 31.

† Clover grazing period November 1 to June 1. Grass grazing period June 1 to November 1.

TABLE 3.—PHOSPHORUS, POTASH AND NITROGEN APPLIED PER ACRE EACH PASTURE YEAR.

Year	Fertilizer Nutrients, Pounds per Acre		
	P_2O_5	K_2O	N
1952	126.0	180.0	142.5
1953	90.0	180.0	192.6
1954	100.0	210.0	226.0
1955*	100.0	180.0	....

* Grazing terminated June 30.

inadequate due to drought (on non-irrigated pastures) or a killing frost occurred in the late fall. Rotational grazing was practiced within the control pastures and within the irrigated pastures. The number of cows kept on pastures was adjusted in accordance with its carrying capacity. Concentrate mixtures were fed in accordance with milk production.

During March, April and May clover supplied most of the grazing material and during the remainder of the year pangola grass was the predominant plant species. In 1952, 1953 and 1954, June 1 was the

TABLE 4.—Irrigated and Non-Irrigated Production in Total Digestible Nutrients, Cow Grazing Days, Date Grazing Began and TDN per Acre Inch of Irrigation Water, 1953, 1954, and 1955.

Grazing Period	Irrigated Pastures				Non-Irrigated Pastures		
	TDN Lbs./A.	Cow Grazing Days/A.	Date Grazing Began	TDN A./In. Irrigation Water	TDN Lbs./A.	Cow Grazing Days/A.	Date Grazing Began
1952 clover	1777	142.0	3-18-52	26.7	1585	124.5	3-18-52
1952 grass	4403	465.0	....	49.7	3630	390.0	....
1953 clover	2390	196.5	3-3-53	53.5	1401	103.0	3-27-53
1953 grass	4296	469.3	....	14.1	4228	448.0	....
1954 clover	3078	216.0	3-2-54	16.6	2970	212.5	3-9-54
1954 grass	4070	369.5	....	17.7	3844	350.3	....

TABLE 5.—Irrigated and Non-Irrigated Production, and Rainfall and Irrigation Totals.

Factors	Irrigated Pasture	Non-Irrigated Pasture
TDN/Acre, Pounds	2662	858
Cow Grazing Days/Acre	205	64
Date Grazing Began and Ended	3-10-56 6-30-56	3-22-56 4-26-56
TDN Increase/Acre Inch Irrigation Water	56.9	....
Number of Irrigations	38	....
Irrigation, Inches	31.68	....
Rainfall, Inches	19.36	19.36
Total Rainfall and Irrigation, Inches	51.04	19.36
Expected Rainfall, Inches*	22.51	22.51

* Average Rainfall at Gainesville 1903 - 1955.

approximate date that pangola grass became the predominant pasture plant species. For that reason the results are presented for the clover period (beginning of grazing through May 31) and the grass period (June 1 until end of grazing season).

The cow days of grazing and total digestible nutrients per acre for the irrigated and non-irrigated pastures and the increase in yield of total digestible nutrients per acre are shown by years, in Table 4.

In the spring of 1955 the experimental procedure was modified to determine the effect of relatively high soil moisture level upon the feed obtained by cattle from white clover pasture. From March 1 through June 30, 1955, water, both rainfall and irrigation, was available to the irrigated pastures at a rate of approximately .30 inch per day with an interval between irrigations of 2 or 3 days. This amount of water maintained the level of soil moisture at or above field capacity in the entire root zone of the pasture plants. Table 5 shows the results of this irrigation study, and rainfall and irrigation amounts.

SUMMARY

Irrigation water applied in amounts and at intervals used in this experiment was adequate to maintain a high level of production from pangola grass - white clover pastures during all seasons of the years included in this experiment irrespective of rainfall amounts and distribution. Irrigation water requirements averaged approximately 20 inches per year for the years 1952, 1953 and 1954. The irrigated pasture produced 21.6 percent more TDN during the clover season and 9.1 percent more TDN during the grass season than non-irrigated pastures for the years 1952, 1953 and 1954 combined.

The 1955 clover season was generally considered "a poor clover year" in the Gainesville area. However, the high level of water applied on the irrigated pastures in 1955 insured a production level which was at least the equivalent of the previous three seasons. The non-irrigated clover treatment in 1955 produced only 32.3 percent as much as the irrigated treatment.

Grazing was started an average of 14 days earlier and a more uniform carrying capacity of cattle was maintained on the irrigated pastures. Irrigated pastures retained high quality forage during dry periods when quality declined in the non-irrigated pastures.

RESULTS OF RESEARCH AND RESPONSE OF CITRUS TO SUPPLEMENTAL IRRIGATION

R. C. J. Koo and John W. Sites *

Recent research on the use of irrigation in the citrus production program has been developed to secure more information on plant-soil-water relationships. Fundamental information is needed on the reactions and physiological changes in plants growing under conditions of soil moisture stress, evapotranspiration losses of soil moisture under grove conditions, and plant responses as reflected in terms of quantity and quality of fruit produced.

This report covers, in a general way, two segments of research work undertaken to date. One includes a quantitative study of water loss in a mature grapefruit grove. In this study, the various sources of water loss were measured so that the percentage of loss due to percolation, evaporation and transpiration could be ascertained. The other research area deals with the effect of applications of supplemental irrigation upon the quality and production of citrus fruits.

From a preliminary study of data collected over a period of years, it was apparent that the quality of citrus fruit produced during any single season is negatively correlated with rainfall (2, 3) and that the degree of correlation which exists appears to be related to the occurrence of specific periods during the growing season when soil moisture tensions would be large or small as affected by rainfall. A brief discussion of results of research conducted in these two areas is presented.

A QUANTITATIVE STUDY OF WATER LOSS UNDER GROVE CONDITIONS

In studying soil moisture-plant relationships, it was felt desirable to ascertain how much water a citrus tree will use over a given period of time and to categorize the remaining water loss not directly associated with the tree. To attempt such work under field conditions necessitates the study of factors over which little control may be exercised. Each factor must therefore be studied separately and the results fitted together to arrive at an answer to the whole problem.

To do this, it was necessary to collect data on many phases of the problem which were only indirectly related to the three categories of water loss included in the discussion in this paper. Runoff was not considered a factor in this study since the work was done on Lakeland fine sand with insufficient slope to result in any appreciable runoff. Soil moisture losses were studied during the period from October, 1951, to February, 1953.

It is almost impossible to directly measure, with accuracy, the amount of water large citrus trees will transpire over a long period of time.

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* Interim Assistant Biochemist, Citrus Station, and Assistant Director, Florida Agricultural Experiment Stations.
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For this reason, it was felt that a reasonably accurate estimate of transpiration could be obtained by subtracting the sum of evaporation and percolation from the total quantity of water lost. A careful record of soil moisture loss and changes was made using six plots, with six trees per plot. Samples from each plot were composited from the six trees at each sampling depth according to a rotational pattern. This eliminated variations due to direction of exposure. Samples were collected just beyond the drip of the trees at depths of 0-6, 6-12, 12-18, 18-24, 30-36, 42-48, 54-60 and 66-72 inches. A six-foot stainless-steel tube approximately one inch in diameter with a hardened tool steel tip was used for sampling. Samples were collected two or three times a week, depending upon the pattern of rainfall. Soil moisture was calculated on an oven-dry weight basis. The moisture gain or loss is reported on the basis of gallons per tree. An acre six inches of soil was assumed to weigh 2,000,-000 pounds and a single tree occupied 625 square feet.

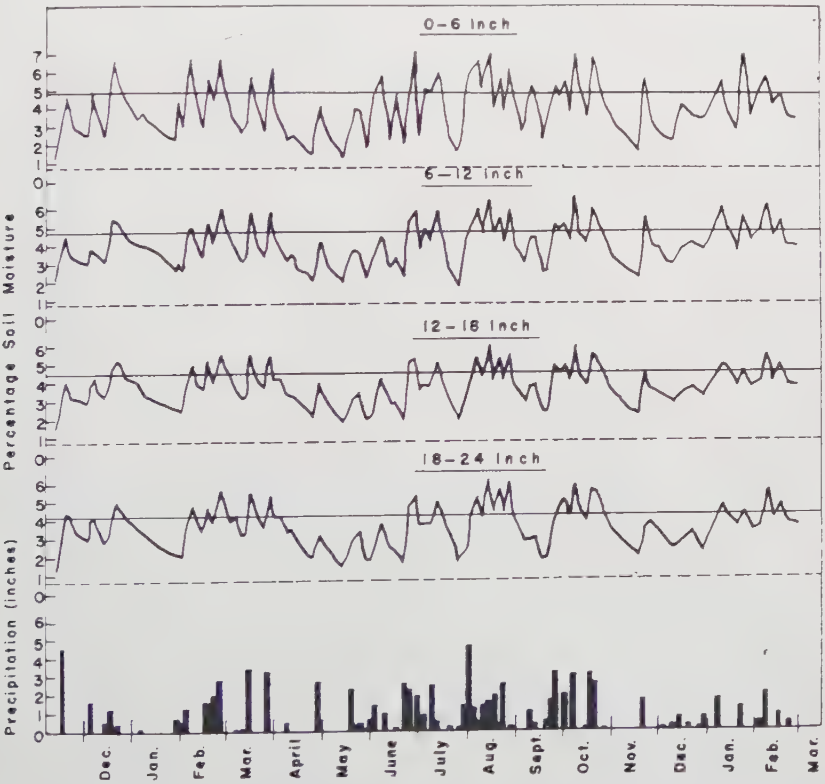

Figure 1. Soil moisture fluctuations at four depths (0-24 inches) and precipitation from November 19, 1951 to February 28, 1953. Field capacity and permanent wilting percentage for different depths are represented by solid and broken lines.[1]

[1] Koo, R. C. J. A study of soil moisture in relation to absorption and transpiration by citrus. Thesis for Doctor of Philosophy Degree, University of Florida. 1953.

Percolation.—Whenever the soil moisture content of a given soil is above its field capacity, the excess gravitational water will percolate away. Under field conditions, percolation and absorption by tree roots takes place simultaneously. Field capacity was measured by thoroughly wetting an area free of root interference. Excess surface evaporation was prevented by covering the sampling area with a large piece of glass, and a 25 x 25 foot water-proofed heavy canvas was used as an overall cover. Soil moisture change to a depth of six feet was measured daily for 35 days.

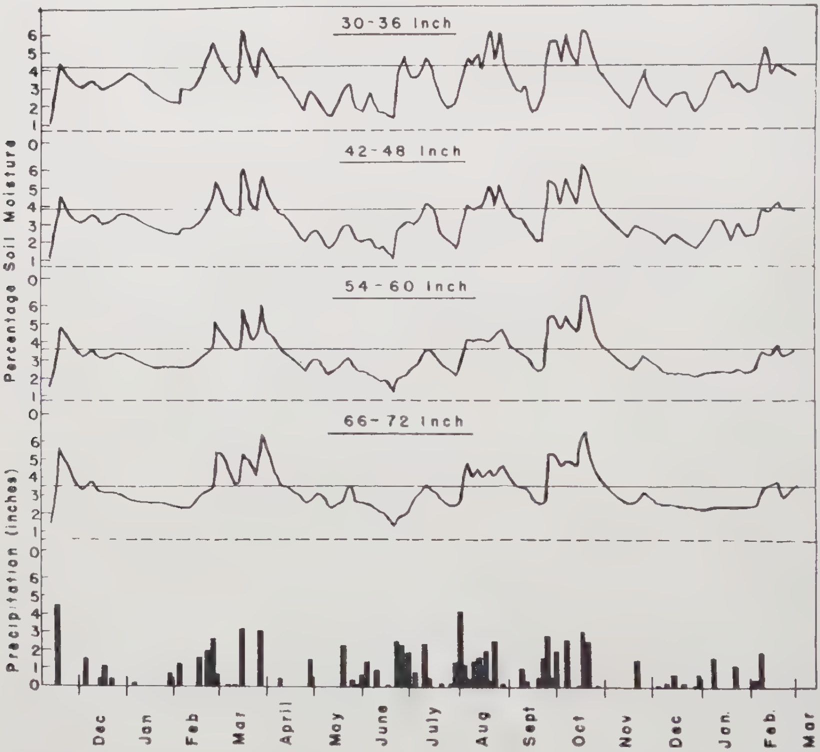

Figure 2 Soil moisture fluctuations at four depths (30-72 inches) and precipitation from November 19, 1951 to February 28, 1953. Field capacity and permanent wilting percentage for different depths are represented by solid and broken lines.[1]

[1] Koo, R. C. J. A study of soil moisture in relation to absorption and transpiration by citrus. Thesis for Doctor of Philosophy Degree, University of Florida. 1953.

Field capacity was obtained for most depths from six to nine days after wetting and these values were represented by the solid lines in Figures 1 and 2. Soil moisture change for the first ten days after wetting for each depth was plotted on common logarithm graph paper. These curves, which showed the rate of downward movement of water due to percolation, were used in the calculation of percolation. The number of days when the soil moisture contents were above field capacity are

shown graphically in Figures 1 and 2. The downward movement shown in Figures 1 and 2 represents chiefly percolation and uptake by roots. The difference in the rate of downward movement between the field capacity curves and those shown in Figures 1 and 2 is due to root absorption.

When the root absorption and surface evaporation values are subtracted from the total moisture loss, the remainder is largely water moved by percolation. Certain errors are contingent with this method of calculation but the data are believed to represent an accurate estimate of percolation loss. A summary of percolation loss from November 19, 1951 to February 27, 1953 is presented in Table 1. Whenever there was an accumulated rainfall of more than 2½ inches within a few days, some percolation would usually occur, depending on the soil moisture content before the rain occurred.

TABLE 1.—PRECIPITATION AND MONTHLY PERCOLATION ON LAKELAND FINE SAND (FROM NOVEMBER 19, 1951 TO FEBRUARY 27, 1953).*

Date	Percolation Gallons per Tree	Precipitation Acre/Inch	No. of Rains More Than 2.5 Inches
11-19-51 - 12-27-51	278	2.77	1
12-17-51 - 1-29-52	0	0.60	0
1-29-52 - 2-27-52	471	5.87	1
2-27-52 - 3-31-52	1746	6 47	2
3-31-52 - 4-28-52	232	2.10	0
4-28-52 - 5-31-52	0	3.08	0
5-31-52 - 6-30-52	46	5.57	1
6-30-52 - 8- 2-52	166	5.63	1
8- 2-52 - 8-30-52	1621	9.30	3
8-30-52 - 10- 1-52	469	6.47	1
10- 1-52 - 11- 3-52	2175	7.77	3
11- 3-52 - 12- 1-52	0	1 33	0
12- 1-52 - 12-29-52	0	0.90	0
12-29-52 - 1-29-53	22	2.80	0
1-29-53 - 2-27-53	48	3.17	0

* Koo, R. C. J. A study of soil moisture in relation to absorption and transpiration by citrus. Thesis for Doctor of Philosophy Degree, University of Florida. 1953.

Evaporation.—An attempt was made to measure evaporation under grove conditions, so that variation in evaporation due to shade offered by trees and their effects on relative humidity could be minimized. Oil drums with removable tops were used for this study. The bottoms of the drums were cut out and the lower edges of the drums were sharpened. Each drum was driven into the ground until the top rim was about two inches above the surface of the soil. This left an undisturbed column of soil free of functional roots.

The drums were located in different parts of the block, inside the canopy of the tree about two feet from the trunk, and about one foot beyond the leaf drip with north, south, east and west exposures. Field capacity of the soil inside the drum at six-inch intervals to depths of two feet were first ascertained.

When the soil moisture content was below field capacity, evaporational loss was calculated simply by taking the average percentage moisture loss of all the drums at the various sampling depths. Since roots were eliminated, the resulting loss was due to evaporation. When the soil moisture content was above field capacity, the loss due to evaporation was ascertained by comparison of the downward movement curves obtained when field capacity measurements were made (tops of drums sealed shut) with those for evaporation (top of drums open). The calculations were made for each drum at each depth and averaged.

The data in Table 2 shows evaporation loss from November, 1951 to February, 1953. These data also indicate that the rate of evaporation was closely associated with temperature and soil moisture content. Statistical analysis showed that the multiple correlation coefficient ($R = 0.710^{**}$) between evaporation, air temperature and percentage soil moisture was highly significant. The regression coefficients indicated that the average daily evaporation should increase 0.319 gallon per 625 square feet per day with an increase in each degree of the monthly mean temperature, and increase 0.443 gallon per day with an increase of one percent in the soil moisture content. Approximately 75 percent of the total evaporation occurred from the upper six inches. This represented about 40 percent of the total moisture loss in that layer.

TABLE 2.—THE RELATION OF EVAPORATION TO TEMPERATURE AND SOIL MOISTURE.*

Period of Time	Evaporation Loss per Tree (625 sq. ft.)		Monthly Mean Temperature Degrees F.	Available Soil Moisture to 24-Inch Depth Percent
	Total Gallons	Daily Average Gallons		
11-19-51 - 12-27-51	154	4.4	62.5	3.06
12-27-51 - 1-29-52	97	2.9	64.4	2.36
1-29-52 - 2-27-52	116	4 0	60.7	4.11
2-27-52 - 3-31-52	258	7.8	67.9	3.29
3-31-52 - 4-28-52	206	7 4	68.7	1.90
4-28-52 - 5-31-52	356	10.8	77.6	2.04
5-31-52 - 6-30-52	351	11.7	83.5	3 32
6-30-52 - 8- 2-52	304	9.2	82.8	3.39
8- 2-52 - 8-30-52	432	15.4	80.8	4 56
8-30-52 - 10- 1-52	403	13.3	81.3	3.30
10- 1-52 - 11- 3-52	176	5.3	73.0	4 16
11- 3-52 - 12- 1-52	108	3.9	65.6	2.14
12- 1-52 - 12-29-52	61	2 2	58.0	2.19
12-29-52 - 1-29-53	176	5.7	60.5	3.45
1-29-53 - 2-28-53	204	6.8	64.3	3.53

* Koo, R. C. J. A study of soil moisture in relation to absorption and transpiration by citrus. Thesis for Doctor of Philosophy Degree, University of Florida. 1953.

Transpiration by Trees.—No attempt was made to measure the rate of transpiration directly in the present study, since it involved too large an undertaking considering the size of the trees. The accuracy of the results would have been questionable if a direct method of measurement had been attempted. The quantity of transpiration in the present study was obtained by substracting the evaporation and percolation losses from

TABLE 3.—A QUANTITATIVE ESTIMATE OF DIFFERENT SOURCES OF MOISTURE LOSS ON LAKELAND FINE SAND PLANTED WITH 15-YEAR-OLD MARSH GRAPEFRUIT TREES. (EXPRESSED IN GALLONS PER TREE).*

Date	Precipitation and Irrigation	Moisture Change**	Water Removed from Soil	Evaporation	Percolation	Transpiration per Tree	Transpiration per Tree per Day
	Gallons	Gallons	Gallons	Gallons	Gallons	Gallons	Gallons
11-19-51 - 12-27-51	1073	L 430	1503	154	278	1071	28
12-27-51 - 1-29-52	232	L 511	743	97	0	646	21
1-29-52 - 2-27-52	2273	G 1197	1076	116	471	490	16
2-27-52 - 3-31-52	2506	L 316	2812	258	1746	818	26
3-31-52 - 4-28-52	813	L 620	1433	206	232	995	36
4-28-52 - 5-31-52	1193	L 296	1489	356	0	1133	34
5-31-52 - 6-30-52	2157	G 255	1902	351	46	1551	53
6-30-52 - 8- 2-52	2336	G 192	2144	304	166	1674	52
8- 2-52 - 8-30-52	3602	G 415	3187	432	1620	1136	41
8-30-52 - 10- 1-52	2506	G 335	2171	403	469	1299	41
10- 1-52 - 11- 3-52	3009	L 852	3862	176	2175	1511	46
11- 3-52 - 12- 1-52	515	L 145	660	108	0	551	20
12- 1-52 - 12-29-52	349	L 230	579	61	0	518	19
12-29-52 - 1-29-53	1084	G 233	831	176	22	653	21
1-29-53 - 2-27-53	1228	G 313	915	204	48	663	22
Total	24877	L 79	25347	3357	7279	14706	
Percent Total Loss			100%	13%	29%	58%	

* Koo, R. C. J. A study of soil moisture in relation to absorption and transpiration by citrus. Thesis for Doctor of Philosophy Degree, University of Florida, 1953.

** Difference between the first and last day percentage moisture readings calculated as gallons of water for a given period. If there is a loss it is added to the precipitation and irrigation. If there is a gain it is substracted from it.

G—Gain. L—Loss.

the total water removed from the soil. A summary of the sources of moisture losses is presented in Table 3. The column under "Water Removed from Soil" was obtained by adding or subtracting the second column from the first column. Transpiration was obtained by subtracting evaporation and precolation from water removed from the soil.

These data show wide variations in the quantity of water transpired in different months. The average daily transpiration for the whole year was 34.2 gallons per tree per day. However, the range varied from 16 gallons a day for the month of February, 1952 to 53 gallons a day for June, 1952. The increase or decrease in the rate of transpiration was closely correlated with the air temperature ($r = 0.834^{**}$).

Although the readily available soil moisture affects the rate of transpiration, this effect is usually only of importance during those periods when soil moisture tensions are high. In general, the correlation between transpiration and the readily available soil moisture was insignificant ($r = 0.062$). When both variants were taken into consideration simultaneously, the multiple correlation coefficient ($R = 0.835^{**}$) was obtained.

EFFECT OF IRRIGATION ON FRUIT QUALITY

As judged by previous experimental work, the external quality of citrus fruit is less affected by irrigation as an integral part of the production program than is the internal quality. There are certain obvious exceptions to this statement. This is especially true where trees may be suffering from an extreme soil moisture shortage and a consequent irrigation will firm the fruit and tend to make it more acceptable for shipment. Also, trees with light crops will have a greater tendency to produce coarse, poorly colored fruit if irrigated sufficiently so that soil moisture is never a limiting factor. However, when trees are bearing a good crop of fruit, the external quality of the fruit is usually not appreciably affected by applications of irrigation where the irrigation is applied previous to any serious drought effects.

Previous research work has shown quite conclusively that irrigation applied to trees which have fruit crops three months old or older will have the effect of reducing the internal quality of the fruit produced(1, 3). Conversely, it has also been shown that drought conditions occurring during the early part of the fruit season (approximately two to three months following bloom) result in a marked increase in the titratable acid content of the juice. But a drought period occurring four to six months following bloom results in a marked increase in both the titratable acid and soluble solids content of the juice(3).

Dates of application of irrigation to three sweet orange varieties at the Citrus Experiment Station for several years are presented in Table 4. The average percent titratable acid and soluble solids content of the juice for the same crop years are shown in Table 5 for irrigated and nonirrigated trees. The effect of the irrigation treatment on the internal quality of the fruit is related to the time the irrigation was applied, the frequency of irrigation in any particular season, and the time at which the variety is normally harvested. Lowering of the soluble solids and titratable acid content of the fruit resulting from irrigation applied later

than the latter part of August or early September appears to be largely a dilution effect. Differences in internal quality resulting in fruit from trees amply supplied with soil moisture as compared to that from trees growing under conditions of moisture stress during the earlier stages of fruit development cannot be accounted for simply on a dilution basis.

TABLE 4.—IRRIGATION APPLICATION SCHEDULE.*

Year	Date of Application	Year	Date of Application
1948	May 25	1951	April 5
1948	June 25	1952	May 13
1948	November 10	1953	May 21
1948	December 7	1954	April 5
1949	March 5	1954	May 13
1949	May 27	1954	September 17
1949	November 9	1955	March 10
1950	February 3	1955	May 6
1950	June 21		

* Irrigation applied at rate of 2 acre inches per application. Water applied when average soil moisture to a depth of four feet was approximately two percent.

EFFECT OF IRRIGATION ON PRODUCTION

Previously reported results of the effect of irrigation on citrus production have been variable. Sites, *et al.* (3) pointed out that results from two irrigation experiments conducted over a period of years indicated that timing of irrigation appeared to be important and that early winter (December, January) irrigations usually resulted in lowering crop yields.

During the 1951-52 and 1954-55 seasons an opportunity was afforded to secure information on the effect of applying irrigation during the period when the trees were either in bloom or very shortly after petal fall. This practice is sometimes referred to by commercial growers as being detrimental. Highly significant increases in yields resulted during both seasons for all three orange varieties included in the experiment, Tables 6 and 7. The increased fruit set resulting from this treatment suggests the desirability of growers irrigating trees at this time during years when drought conditions prevail. It further offers a possible means of reducing the large amount of "off-bloom" fruit which frequently results as an aftermath of drought conditions when they occur during the blooming period.

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1. Hilgeman, Robert E. Irrigation of Valencia Oranges. California Citrograph **36**: 370-372. 1951.

2. Sites, John W. Internal Fruit Quality as Related to Production Practices. Proceedings of the Florida State Horticultural Society **60**: 55-62. 1947.

3. Sites, John W., Herman J. Reitz and E. J. Deszyck. Some results with irrigation research with Florida citrus. Proceedings of the Florida State Horticultural Society **64**: 71-79. 1951.

TABLE 5.—The Effect of Irrigation Application on the Internal Quality of Three Sweet Orange Varieties.†

Year	Brix						Percent Acid					
	Hamlin		Pineapple		Valencia		Hamlin		Pineapple		Valencia	
	I	NI	I	NI	I	NI	I	NI	I	NI	I	NI
1948-49	9 80	10.25**	11.01	11.72*	11.45	12.15	0.84	0.89**	1.05	1.14**	0.96	1.00*
1949-50	8.63	9.05**	9.48	10.85**	10.65	11.59**	0 86	0.98	0.90	0.98**	0.83	0.96**
1950-51	9 53	9.59	11 34	11.30	10.39	10.70	0.93	1.06**	0.96	1.07**	1.00	1.09**
1951-52	9.78	9.86	10.09	10.26	11.23	11.65**	0 95	0.97	1 04	1.03	0.94	0.97*
1952-53	10.71	10.81	11.73	12.04**	12.19	12.36*	0.97	1.02**	1.04	1.15**	1.08	1.10
1953-54	9 95	10.21	10.78	11.10**	11.38	12.13**	0.92	0.96	1.04	1.08	0.94	0.99*
1954-55	10.93	11.36**	11.78	12.13**	11.23	11.70**	1.03	1.13**	1.10	1.20**	0.95	1.01**

† Values represent seasonal averages of samples taken at approximately three-week intervals beginning before fruit of each variety would pass legal maturity and continuing until approximately two months after legal maturity was attained.

** Significantly different at 1% level.

* Significantly different at 5% level.

I — trees irrigated.

NI — trees not irrigated.

TABLE 6.—Effect of Irrigation Applications on Production of Three Varieties of Sweet Oranges, 1951-52.

Treatment	Plot	Average Boxes/Tree	Total Boxes/Plot	No. Trees
		Hamlin Oranges		
Irrigation	1	9 93	149	15
	3	8.42	101	12
	5	8.06	145	18
Box Avg.		8.78*	Sum 395	Sum 45
No Irrigation	2	8.63	138	16
	4	7.29	124	17
	6	8.41	143	17
Box Avg.		8.10	Sum 405	Sum 50
		Pineapple Oranges		
Irrigation	1	7.14	179	25
	3	6.41	141	22
	5	5.80	134	23
Box Avg.		6.47**	Sum 453	Sum 70
No Irrigation	2	6.08	152	25
	4	5.57	123	22
	6	5.08	127	25
Box Avg.		5.21	Sum 402	Sum 72
		Valencia Oranges		
Irrigation	1	6.78	102	15
	3	6 35	95	15
	5	6.07	91	15
Box Avg.		6.40**	Sum 288	Sum 45
No Irrigation	2	5.50	83	15
	4	5.40	81	15
	6	4.73	71	15
Box Avg.		5.21	Sum 235	Sum 45

* = Significance at 5% level.
** = Significance at 1% level.

TABLE 7.—EFFECT OF IRRIGATION APPLICATIONS ON PRODUCTION OF THREE VARIETIES OF SWEET ORANGES, 1954-55.

Treatment	Plot	Average Boxes/Trees	Total Boxes/Plot	No. Trees
Hamlin Oranges				
Irrigation	1 3 5	8.19 7.66 7.71	147.50 145.50 177.25	18 19 23
Box Avg.		7.84**	Sum 470.25	Sum 60
No Irrigation	2 4 6	7.03 6.42 7.18	140.50 134.75 158.00	20 21 22
Box Avg.		6.88	Sum 433 25	Sum 63
Pineapple Oranges				
Irrigation	1 3 5	6.49 5.83 6.00	162.25 145.75 144.00	25 25 24
Box Avg.		6.11**	Sum 452 00	Sum 74
No Irrigation	2 4 6	6.05 5.30 4.46	151.25 127.25 111 50	25 24 25
Box Avg.		5.27	Sum 390.00	Sum 74
Valencia Oranges				
Irrigation	1 3 5	4.73 4.27 5.33	71.00 64.00 80.00	15 15 15
Box Avg.		4.78**	Sum 215.00	Sum 45
No Irrigation	2 4 6	3 83 4.03 2.88	57.50 60.50 43.25	15 15 15
Box Avg.		3.58	Sum 161.25	Sum 45

** = Significance at 1% level.

SYMPOSIUM: PASTURE MANAGEMENT

Thursday, December 1, 8:30 A.M.

D. E. McCloud,* Moderator

WINTER FEED ON EVERGLADES PASTURE

R. J. Allen, Jr., D. W. Beardsley and D. S. Harrison **

Grazing trials at the Everglades Experiment Station have shown that the carrying capacity of pastures on the organic soils of the area averages from two to three yearling animals per acre on an annual basis. They also show, however, that seasonal carrying capacity fluctuates widely, from as high as five animals per acre during summer months to as low as none for periods following frosts during the winter months. It is obvious, therefore, that winter feed on Everglades pastures is one of the cattlemen's most serious problems, since it is obviously impractical to vary the numbers of animals to match the seasonal variation in pasture forage production.

This seasonal variation of carrying capacity is generally greater in the Everglades than on the sand land pastures of south Florida, because it is not possible to control spring and summer production peaks on the organic soils by staggered applications of nitrogen fertilizer, and because pastures on the organic soil areas are more subject to injury from winter frosts. The problem is further aggravated by the great cost of establishing adequate water control systems and by generally higher per-acre taxes. It is therefore more than ever necessary that a forage management program be devised which will compensate for seasonal yield fluctuations, produce a maximum of forage per acre, waste a minimum of this forage, and keep operating costs as low as possible. A program of this nature would permit the cattleman to operate on a planned sale basis, and would practically eliminate the usually unprofitable forced sales which have been all to common in the past, due to weather conditions and shortage of winter feed.

Several ways of at least partially supplying adequate winter feed on Everglades pastures without buying from "outside" are as follows:

1. Delayed grazing, or holding ungrazed pastures until early winter.
2. Planting winter annual crops for temporary supplemental pasture or chopped green feed.
3. Preserving excess summer pasture growth, or other crops, as silage.
4. Interplanting winter annual crops into established pasture sod.

The first two of these practices have been used in the Everglades but have not proved entirely satisfactory in solving the winter feed problem. Recent emphasis at the Everglades Station has been placed on investigation of methods 3 and 4.

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* Associate Agronomist, Agricultural Experiment Station, Gainesville, Florida.
** Assistant Agronomist, Assistant Animal Husbandman and Assistant Agricultural Engineer, Everglades Experiment Station, Belle Glade, Florida.

DELAYED GRAZING

Delayed grazing can be used to supply some forage, or maintainence roughage, in late fall or early winter, but cannot be depended on throughout the winter, or for any long period of time. Its principle advantage is that there is practically no additional operating cost. However, all of the principal Everglades pasture forages, St. Augustinegrass, pangolagrass, paragrass, and caribgrass, when allowed to grow for too long a time, lose lower leaves and become relatively tall, stemmy, and overmature, with consequent wasting of forage and decrease of quality. The latter three may be lost to frost any time after early December. Observations also indicate that this practice tends to delay the return of these grasses to full production in late winter and early spring.

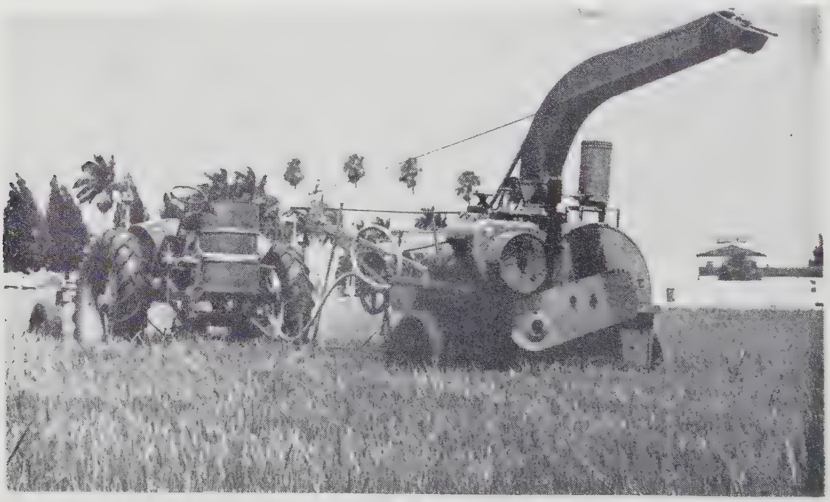

Figure 1.—Equipment for applying silage preservatives mounted on grass harvesting equipment. Star-wheel fertilizer hopper for applying sodium meta-bisulphite is mounted over the feed rolls on the right side of the machine. Molasses barrel and pump are mounted on the tractor with large diameter high pressure hose leading to perforated pipe at the end of the discharge chute.

TEMPORARY WINTER PASTURE

Temporary supplemental winter pasture plantings will give good yields of excellent forage at least by the end of January, and as early as December if weather conditions permit planting early in October. This practice requires the various operations of land preparation which involve relatively high operating costs, and land so used during the winter is quite apt to lay idle during the summer. When temporary winter forage crops are grown they are generally grazed as pastures, but high yielding crops may be utilized more efficiently by harvesting mechanically and feeding as chopped green feed. However, this may not be an economical practice with beef cattle under Everglades conditions.

GRASS SILAGE

Grass silage deserves more emphasis for several reasons. It may be necessary to mow pastures one or more times during the summer to keep the grass from becoming too tall and coarse and this essentially wastes forage. Other silage crops, such as corn or sorghum are not considered since they require extra labor and extra land while excess grass is "there for the harvesting." Little attempt has been made to preserve excess grass as hay because the south Florida climate, especially in the Everglades, is not suitable for making hay without the expense of artificial drying and special storage facilities.

The practice of making silage does require considerable outlay for specialized equipment, but when properly handled gives the greatest insurance of having a supply of good winter forage available at any time it is needed. It obviously has none of the disadvantages of delayed grazing, nor is it necessary to wait for its availability until well into the winter season, as with winter annual grazing crops. The principle objections to grass silage, which were high labor costs of harvesting and feeding, and uncertainty of proper preservation, have been overcome by modern machinery, self-feeding silos, and the proper use of preservatives.

Figure 2.—Filling bunker silo in 1955. Use of track type tractor allowed filling wagons to capacity regardless of the height of the stack. Tank in the foreground has a pump for transfer of molasses to the barrel on the harvesting tractor.

In the summer of 1954, above ground, open-end bunkers, 12 feet wide, 6 to 7 feet high, and 48 feet long, were built of posts and woven wire fencing in four pastures of St. Augustinegrass, pangolagrass, paragrass, and caribgrass, and the cattle either fenced into one-half of each pasture or concentrated into other pastures. When these grasses were judged to be in the proper stage, they were harvested with a direct-cut forage harvester. The loaded wagons were pulled through the bunkers and the chopped grass dumped by means of a power-take-off unloading mechanism. Preservatives were applied after the grass had been leveled off

in the bunkers. Molasses was diluted with 1 part water to 3 parts molasses and sprayed by hand from a one-inch hose onto one-half of the grass, or 24 feet of the bunker, at approximately 100 pounds per ton of grass. Sodium meta-bisulphite was spread by hand at 8 pounds per ton onto the other half, and raked in lightly to get better distribution. The grass was packed with a heavy wheel tractor.

The silos were opened in the latter part of December and stanchion-like self-feeding gates were installed. The labor involved in self-feeding from these bunkers consisted of daily inspection, and, when necessary, throwing off top and side spoilage and moving the gates. Intermittent light frosts in December, January and February eliminated practically all grazing from pangola, para and caribgrass. The animals in these pastures received practically all their feed as grass silage from about December 25 to the end of February, and they remained in very good condition throughout this period, even those with nursing calves showing no appreciable loss in weight. After February it was necessary to move these herds to temporary pasture, indicating a need either for more silage or for late winter grazing in these pastures. The St. Augustinegrass pasture furnished a limited amount of grazing throughout the winter and this silage lasted well into March, and it was not necessary to move this herd.

Figure 5. Yearling steers self-feeding on pangolagrass silage. Self-feeding gate with both vertical and horizontal bars is the most satisfactory. Building paper liner did not prove to be of practical value.

In 1955 equipment was added to the forage harvesting machinery to mechanize the application of preservatives. A 55 gallon drum, which was filled from a supply tank on a trailer, and a PTO driven pump capable of handling undiluted molasses, were mounted on the tractor. A high pressure one inch hose was run from the pump to a perforated pipe T mounted over the end of the harvester discharge chute. The molasses was applied to the chopped grass as it was blown into the wagon. A star-wheel fertilizer hopper mounted over the harvester feed rolls delivered

sodium meta-bisulphite to the grass as it entered the blower. Molasses treated grass was dumped and spread in one half of each bunker, and bisulphite treated grass in the other half. A crawler tractor was used to handle the wagons in the bunkers and to pack the grass. Labor was reduced to two tractor drivers and a "working supervisor", who measured preservatives, assisted in spreading the grass, and took care of all other necessary details of operation. An average of 40 tons of chopped grass per day was put up at a cost of less than $2.00 per ton for labor, fuel, and preservative.

Figure 4.—Ryegrass interplanted into paragrass pasture and protected from grazing until well established. Foreground was broadcast seeded.

All of the pasture grasses made good silage with either of the preservatives. Spoilage in these wire side bunkers was estimated at 30% to as high as 40%, and this increased the above mentioned cost to slightly over $3.00 per ton for the silage available for feeding out during the winter. A bunker with airtight sides would save considerable spoilage but would be considerably more expensive to construct.

A higher or wider stack would also reduce the per cent of spoilage, but the height is limited by the reach of the animals through the self-feeding gates, and the width by the number of animals to be fed at the silo. At least three, and preferably about six inches should be eaten from the face each day to prevent molding of exposed silage. Twelve to fourteen feet in width has proved to be satisfactory for self-feeding the Everglades Station breeding herds of 25 to 30 mature animals.

For the 1955-56 season grass silage has been made in the same pastures, but two bunkers have been filled in the St. Augustinegrass pasture and the caribgrass bunker has been widened to 14 feet. Late winter

grazing is expected from winter annual crops which have been interplanted into the pangolagrass, paragrass, and caribgrass pastures.

INTERPLANTING

Interplanting of winter annual crops into established pasture sods in contrast to overseeding by broadcasting, is a relatively new development in pasture research. It requires special equipment in the form of a fertilizer and seed drill capable of cutting narrow furrows into pasture sod without any great disturbance or damage to the sod.

Figure 5.—Oats interplanted into pangolagrass and protected from grazing until well established.

Obvious advantages of this practice are that it eliminates land preparation and utilizes present pasture acreage while the permanent grasses are relatively dormant. Seed may be planted into the ground and fertilizer placed beneath the seed at the same time. This eliminates to a great extent the uncertainty of broadcast seeding which is much more dependent on favorable weather conditions for germination and seedling establishment. The fertilizer, being applied in bands under the seed, helps the seedlings to make faster early growth, and to compete with the pasture grasses much better than when both seed and fertilizer are broadcast.

In the fall of 1951 various winter annual grasses and legumes were interplanted into about four acres of each of the pastures which had been cut for silage, and a part of these plantings fenced off to control grazing. Observations indicate that the grasses should be mowed or grazed quite close prior to planting, and that for best results, seedlings should be protected from grazing until they are well established. None of the crops planted in the unprotected area furnished any practical amount of grazing

although some did manage to survive. In the fenced area, oats, ryegrass, and alfalfa were the most satisfactory, with the oats being the only one to make even a fair stand in the dense St. Augustinegrass sod. However they failed to recover after a short period of intensive grazing in late January.

Ryegrass is probably the most satisfactory crop available at present in regard to germination, seedling establishment, and ability to stand up under continuous grazing. It appears that oats and alfalfa will require a carefully controlled rotational grazing program for best results.

The results so far with interplanting have shown sufficient promise to warrant setting up a more detailed study concerning time of planting, necessary pasture management, most compatible crops, row spacing, seeding rates, fertilizer rates, and machinery modifications necessary under Everglades conditions. This practice should furnish grazing from midwinter on into spring with reasonable reliability, but early winter, or December grazing will be more difficult to obtain due to the necessity of planting early while the permanent pasture grasses are still growing aggressively. In this early winter season, grass silage might be used most effectively since it can be made available at any time it is needed.

It is believed that a combination of these two practices, grass silage and interplanting, along with a good fertility program, will insure a constant supply of good quality feed for a reasonably constant number of animals throughout the year. It should then be possible for the cattleman to plan his operations and his sales according to market conditions rather than weather conditions and feed supply.

EFFECT OF NITROGEN FERTILIZATION ON THE PRODUCTION OF PANGOLAGRASS AND BAHIAGRASS

A. T. Wallace, G. B. Killinger, R. W. Bledsoe and D. B. Duncan *

INTRODUCTION

Pangolagrass (*Digitaria decumbens*) and Pensacola Bahiagrass (*Paspalum notatum* va.) were introduced into Florida during the 1930's and were released to farmers in the state in 1943. These two relatively new pasture grasses immediately became popular with cattlemen, who rapidly increased their acreages. By 1955 there was approximately a half million acres of Pangolagrass and three quarters of a million acres of Pensacola Bahiagrass growing in the state.

Although several research workers (1, 4, 5) have conducted fertility experiments with Pangolagrass and Pensacola Bahiagrass, the production capacity of these two grasses have never been fully exploited. It was with this in mind that a detailed experiment involving rates of phosphorus and potassium and rates, sources and time of application of nitrogen was planned.

EXPERIMENTAL PROCEDURE

The experiments were conducted on uniform fields of Pangolagrass and Pensacola Bahiagrass at the Beef Research Unit near Gainesville. When the experiments were started in 1950, the sods were two years old. The soil type was Leon fine sand. Uniform applications of dolomitic limestone and fertilizer were applied to the soil before the grasses were planted and minor elements applied after the sods had become established.

The design used was a split plot with four splits. The analysis of variance is presented in Table 1. A summary of the treatments and the notation used for each are as follows:

2 rates of PK	$PK_1 = 0\text{-}60\text{-}60$
	$PK_2 = 0\text{-}120\text{-}120$
2 sources of nitrogen	$S_1 = NaNO_3$
	$S_2 = (NH_4)_2\ SO_4$
5 times of nitrogen application ..	T_1 = March and June
	T_2 = March and August
	T_3 = March, June and August
	T_4 = March, June and October
	T_5 = January, March, May, July, September and November
5 rates of N	R_1 = 30 lbs. per acre per year
	R_2 = 60 lbs. per acre per year
	R_3 = 120 lbs. per acre per year
	R_4 = 240 lbs. per acre per year
	R_5 = 480 lbs. per acre per year

* Assistant Agronomist, Agronomist, Associate Director, and Professor of Agronomy, respectively.

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TABLE 1.—THE F. RATIOS FOR ALL TREATMENTS AND TREATMENT INTERACTIONS FROM THE ANALYSES OF VARIANCE FOR BOTH GRASSES FOR EACH YEAR.

Source of Variation	d.f.	Pangola			Bahia		
		1950	1951	1952	1950	1951	1952
Replications	1						
P. K. levels	1	18.40	435.98**	9.48	363.33*	1.29	0.16
Error (a)	1						
Time of N application	4	20.34**	5.84**	22.22**	12.13**	1.16	3.10
Time x P.K.	4	0.22	0.76	1.42	1.92	1.06	0.98
Error (b)	8						
Source of N	1	122.51**	15 18**	0.93	0.70	15.20**	0.11
Source x Time	4	5.93**	0.74	1.14	1.32	0.48	1.05
Source x P.K.	1	0.08	0.05	.81	0.31	3.59	2.55
Error (c)	14						
Rate of N application	4	622.83**	183.71**	143.03**	200.38**	305.36**	94.13**
Rate x Source	4	6.09**	3.39*	2.60*	2.50*	25.55**	1.50
Rate x Time	16	2.81**	3.16**	3.34**	0.90	1.14	2.84**
Rate x P.K.	4	2.15	1.49	2.67*	0.44	2.20	2.20
Error (d)	132						
Harvests	3	124 94**	9.33**	304.55**	217.95**	264.70**	558.90**
Harvests x Rate	12	19.06**	6.47**	19.20**	27.29**	36.16**	15.84**
Harvests x Source	3	0.23	0.34	0.73	3.20**	3.42*	2.44*
Harvests x Time	12	66.62**	30.54**	28 22**	26.77**	14.23**	6.63**
Harvests x P.K.	3	0.97	3.98**	7.06**	1.13	0.60	2.16
Error (e)	567						
C.V.		9.2%	11.4%	11.0%	6.8%	4.9%	6.4%

The phosphorus, derived from 20 percent superphosphate, and the potash, derived from 60 percent muriate of potash, were applied in January of each year.

The experiment was conducted over three years, 1950, 1951, 1952. All plots were harvested at the same time, except in 1950, when the first harvest was restricted to certain plots which had made exceptional early growth. All plots were included in subsequent harvests. A sickle-type mower was employed.

Plot size was 5 x 15 feet. Eighteen inches were cut off both ends of each plot and discarded at each harvest. This left 12 feet of plot for harvest, and a 36-inch strip was then cut lengthwise on each plot. The remaining vegetation was mowed and removed from the plots. When harvested, all grass had begun to produce seedheads with an estimated 10 to 20 percent seedhead population.

All samples of grass were dried in a heated, forced air drier at 130 to 140°F. and yields were expressed as weight of dry material per acre. Total moisture remaining in samples was between five and six percent.

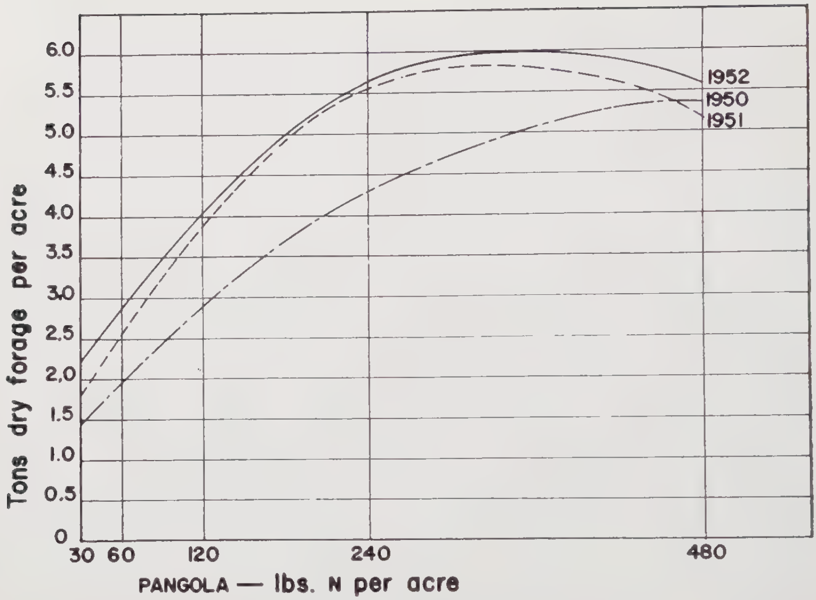

Figure 1.—Fitted curves showing yield of Pangolagrass for each year which are based on significant linear and quadratic trends.

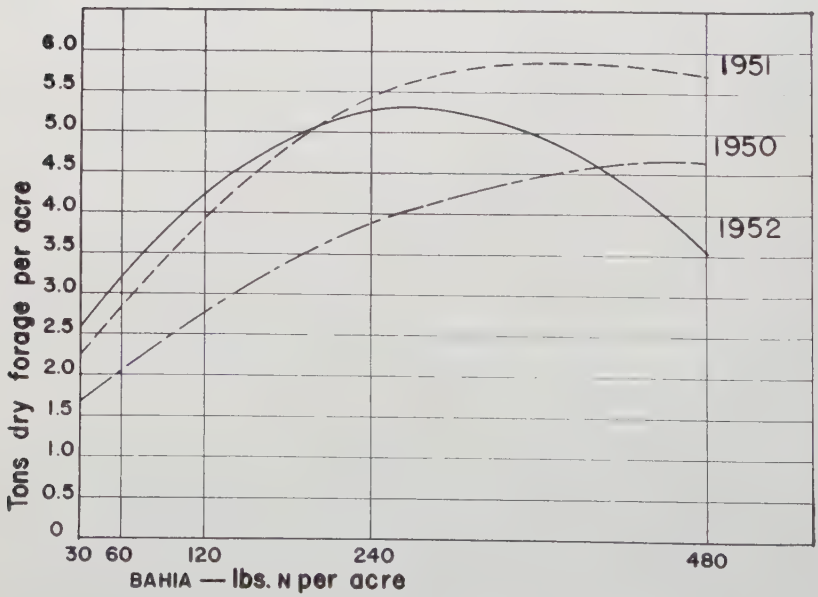

Figure 2.—Fitted curves showing yield of Bahiagrass for each year which are based on significant linear and quadratic trends.

It may be noted that the 240 and 480 pound rates of nitrogen caused a reduction in stand of Pangolagrass during the 1950-51, 1951-52, and 1952-53 winter months as evidenced by the stand of grass in the spring of '51, '52, and '53. Stands of Pangolagrass rapidly reestablished on these plots and were ready to harvest with the remaining plots.

Hereafter, Pangolagrass and Pensacola Bahiagrass will be referred to as Pangola and Bahia, respectively.

RESULTS AND DISCUSSION

In this experiment, Pangola showed more variation from treatment to treatment and a larger coefficient of error variation than Bahia.

By far the largest sources of variation between the treatments came from two things: rates of nitrogen applied and from harvests. These differences are indicated in Table 1, which presents the F-ratios from the analyses of variance for both grasses and for all three years. Although it can be seen that the F-ratios are larger in some years than in others for the nitrogen rates and for harvests, they are nevertheless quite large each year.

The production of the grasses with different rates of nitrogen is presented for each year in Figures 1 and 2. The curves in these two Figures were computed [1] from significant linear and quadratic trends(2) found in the regression of production on nitrogen rates. In general, as is indicated in Figures 1 and 2, there is an increase in production of forage for each additional increment of nitrogen added except that at the higher rates the added increments are less efficient in increasing forage production than the lower rates. This fact is even more striking in Bahia.

Other than the F-ratios for rate of nitrogen and harvests, the only F-ratios that are consistently significant in all three years for both grasses are those for the two interactions, Harvests x Rate and Harvests x Time. The F-ratios for these two interactions are rather small even though consistently significant. These interactions indicate that the influence of rate and time of nitrogen applications on yield differs somewhat from one harvest to another. They indicate that to a small extent there is a varying optimum rate and time of nitrogen application for each harvest.

The significant F-ratios for the interactions, Rate x Source and Rate x Time, indicate that the plants did not respond alike to all rates of nitrogen, for both sources of nitrogen, or to all times of nitrogen application. In fact for the most economic nitrogen utilization these ratios would indicate that each source had a different optimum rate and time for applying it. However, when the data were analyzed in a combined analysis (Table 2), the interactions averaged out so that there were no significant Rate x Source or Rate x Time interactions. The insignificance of these interactions in the combined analysis points out that in the average at all rates of nitrogen application the plants responded alike to both source of nitrogen and at all five times of application.

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[1] The fitted curves are given by $\overline{Y} = \overline{y} + b_L x_L + b_Q x_Q$, where $\overline{y}$ = mean for the treatment, b_L and b_Q are the linear and quadratic regression coefficients and X_L and X_Q are the linear and quadratic polynomials respectively.

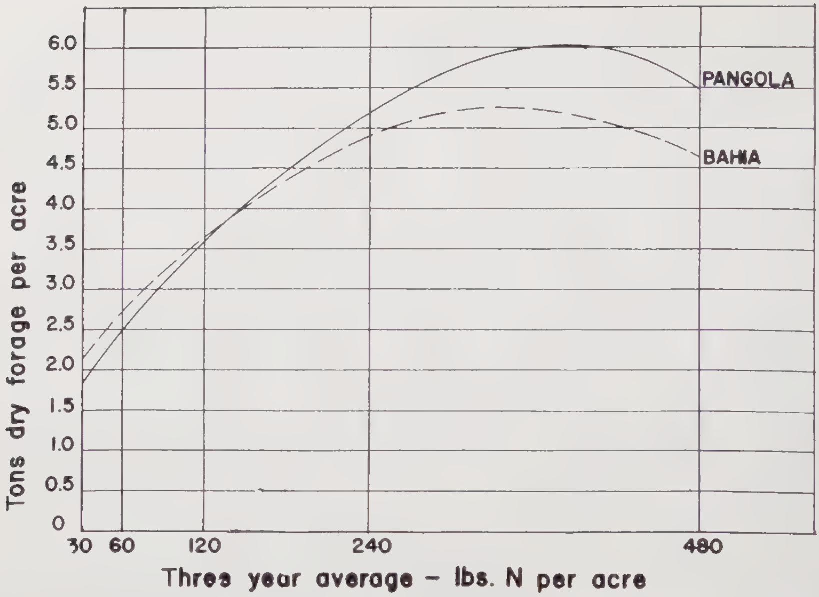

Figure 3.—Fitted curves showing the average yield of Pangolagrass and Bahiagrass which are based on significant linear and quadratic trends.

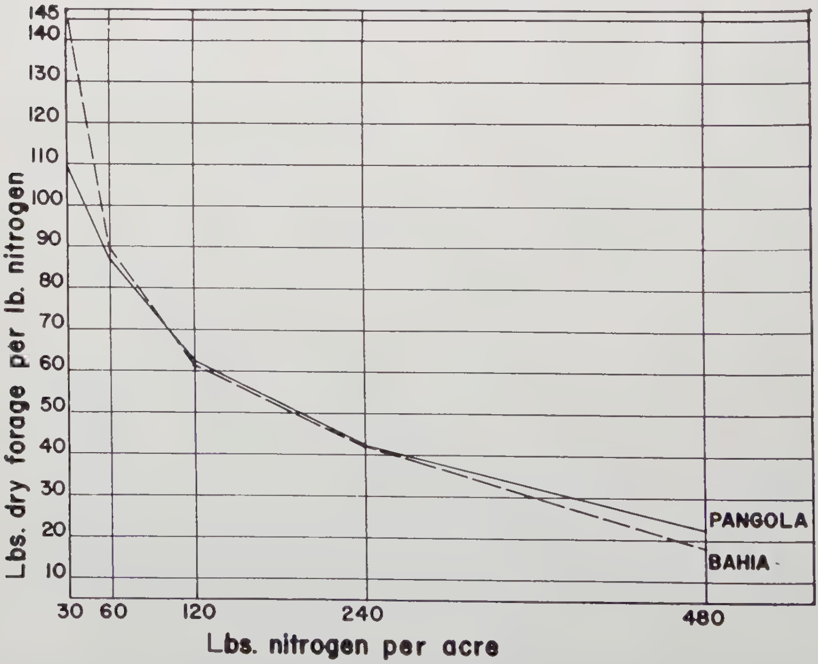

Figure 4.—Average yield of dry forage per pound of nitrogen for Pangolagrass and Bahiagrass.

TABLE 2.—THE F. RATIOS FOR ALL TREATMENTS AND TREATMENT INTERACTIONS FROM THE ANALYSES OF VARIANCE FOR BOTH GRASSES OVER ALL YEARS.

Source of Variation	d.f.	Pangola Over Years	Bahia Over Years
Replications	1		
P.K. levels	1	13.19*	0.11
Error (a)	1		
Time of N application	4	1.15	2.34
Time x P.K.	4	0.63	1.29
Error (b)	8		
Source of N	1	2.08	0.41
Source x Time	4	0.78	0.50
Source x P.K.	1	0.95	1.27
Error (c)	14		
Rate of N application	4	16.67**	9 69
Rate x Source	4	0.62	0.89
Rate x Time	16	0.90	0 84
Rate x P.K.	4	1.28	1.53
Error (d)	132		
Years	2	86 57**	17.18**
Years x Rate	8	8.52**	57.45**
Years x Source	2	15.78**	8.51**
Years x Time	8	14.40**	3.43**
Years x P.K.	2	0.81	2 30
Years x Rate x P.K.	8	1.55	1 09
Years x Rate x Time	32	3.36**	2.08**
Years x Rate x Source	8	4.01**	10 41**
Years x Source x P.K.	2	0.20	1.54
Years x Source x Time	8	1.54	1.55
Years x Time x P.K.	8	1.45	1.01
Error (e)	312		
C.V.		9.2%	7.0%

The only treatments that had significant effects over all three years were PK levels for Pangola and Nitrogen rates for both grasses. This is pointed out in Table 2, which gives F-ratios for the combined analyses. (The detailed methods for making the appropriate tests of significance in the combined analysis and for obtaining the appropriate degrees of freedom and thus these F-ratios will be presented in a later paper.) The non-significant PK level F-ratio for Bahia points out that the 0-120-120 rate was not reliably better than the 0-60-60 rate. Also the non-significant Time and Source F-ratios indicate that over a period of years there would be no differences in plant responses to the two sources of nitrogen or to the times at which the nitrogen was applied. In other words, over the period of years, one source of nitrogen would be as good as the other and one time of application is as good as the other.

The large variation due to nitrogen rates (Table 2) was examined for polynominal trends. Highly significant linear and quadratic trends were found leaving non-significant residuals (see Table 3). The fitted

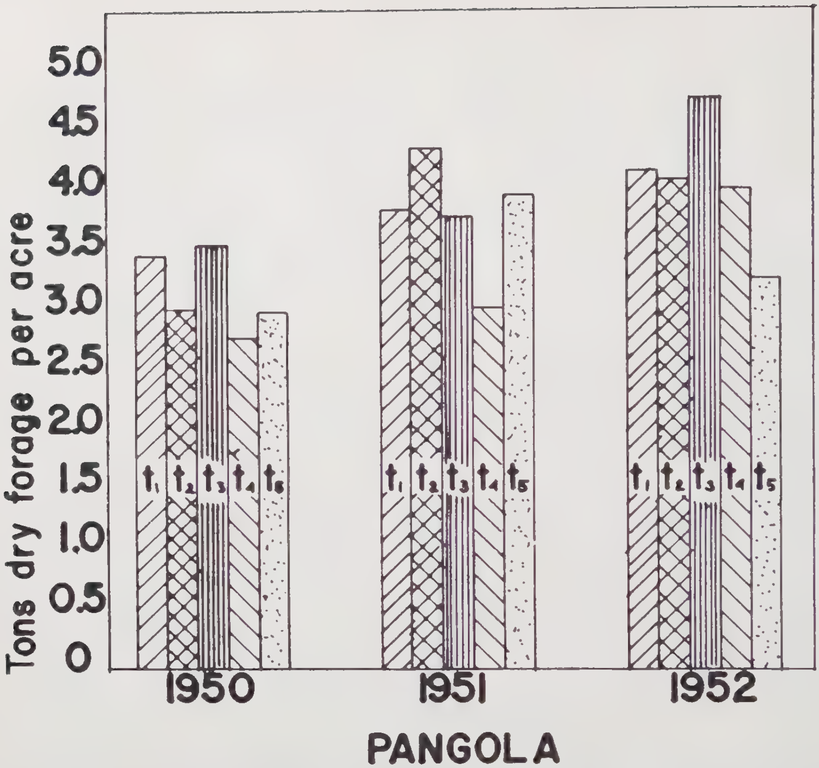

Figure 5.—Bar graph showing the production of Pangolagrass for each time of nitrogen application for each year.

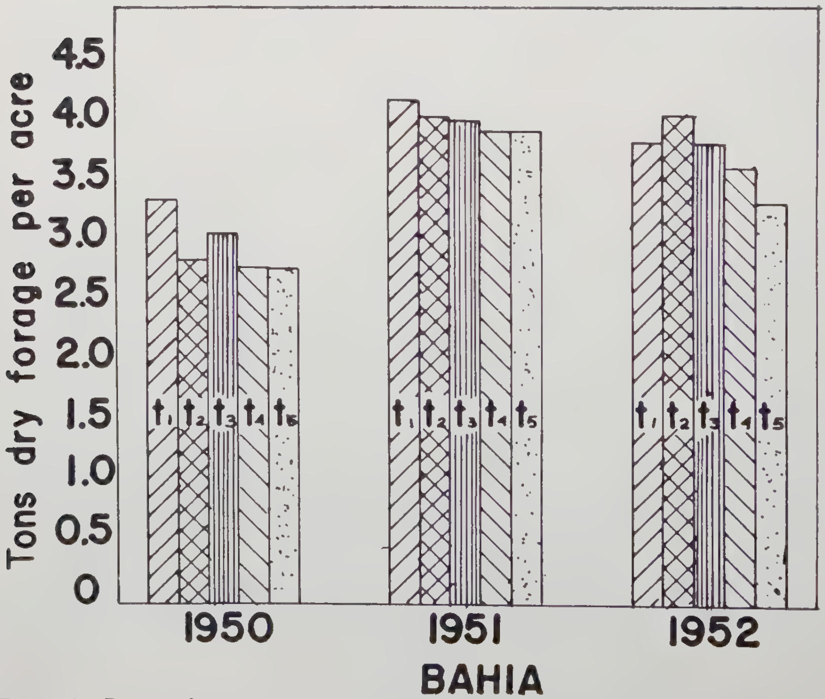

Figure 6.—Bar graph showing the production of Bahiagrass for each time of nitrogen application for each year.

curves based on the significant trends are shown in Figure 3. The non-significance of the residuals indicates in each case that the given curves are as good a fit as can be made. These significant linear trends show that over all years for each added increment of nitrogen there was an increase in forage production. The significant quadratic trend indicates that at the higher rates, the added increments were less effective in stimulating forage production than at the lower rates. These curves also indicate that at the lower rate (30 lbs. of nitrogen) Bahia was more efficient in nitrogen utilization, while at the higher rates (480 lbs.) of nitrogen, Pangola was the more efficient. This is better illustrated in Figure 4 which presents curves showing the production of dry forage per pound of nitrogen applied for both grasses. At the 60, 120 and 240 pound rates, there were no difference in the efficiency of nitrogen untilization between the two grasses.

TABLE 3.—The Linear and Quadratic Variances for the Rate of Nitrogen Treatment for Each Grass Over All Years.

Source of Variation	Pangola Over Years d.f.	Sum of Squares	Mean Square	F Ratio
Rate of N application	4	11,922,693		
Linear	1	9,273,837	9,273,837	207.28**
Quadratic	1	2,547,878	2,547,878	56.95**
Residual	2	100,978	50,489	1.12
Error	132		44,739	
	Bahia Over Years			
Rate of N application	4	5,799,384	3,845,954	25.66**
Linear	1	3,845,954	1,951,363	13.02**
Quadratic	1	1,951,363	10,335	.07
Residual	2	20,677	149,859	
Error	132			

The variation of F-ratios from year to year which was observed in Table 1 for the different treatments is reflected in the large interactions with years in Table 2. In the latter table it can be seen that the three interactions (Year x Rate, Year x Source and Year x Time) are significant over all years for both grasses. The magnitudes of the Y x R, of the Y x T and of the Y x S interaction are illustrated in Figures 1 and 2, 5 and 6, and 7 and 8 respectively.

CONCLUSIONS

The fact that the PK level ratio in Table 2 is significant only at the 5% level for Pangola is rather surprising, especially since it is known (3) that Pangola requires rather high quantities of potash for maximum growth. However, Gammon and Blue(3) have reported that Pangola has a high affinity for "luxury consumption" of potash. Keeping this in mind and recalling that the PK applications were made at the beginning

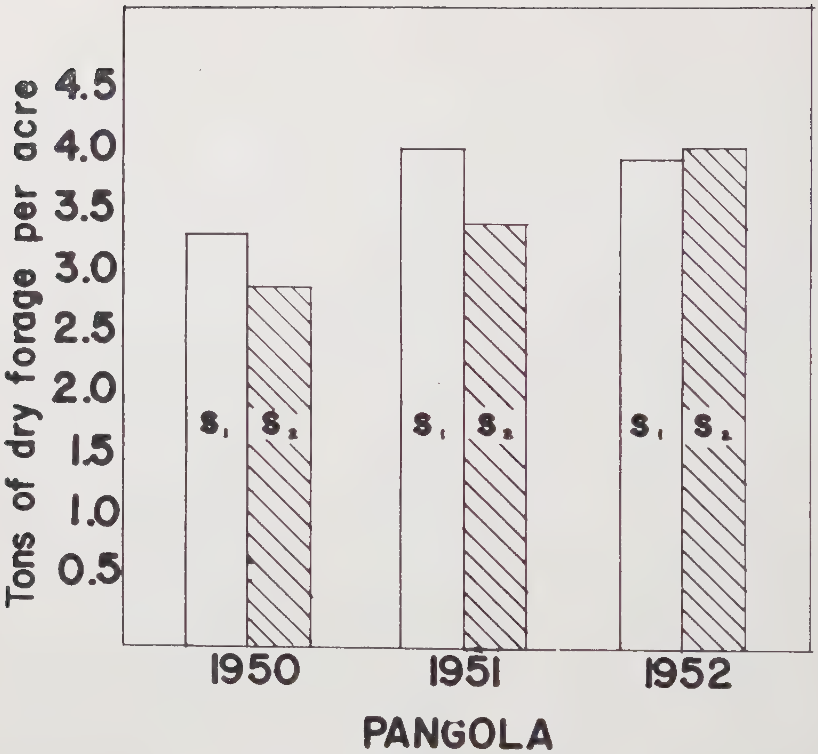

Figure 7.—Bar graph showing the production of Pangolagrass for each source of nitrogen for each year.

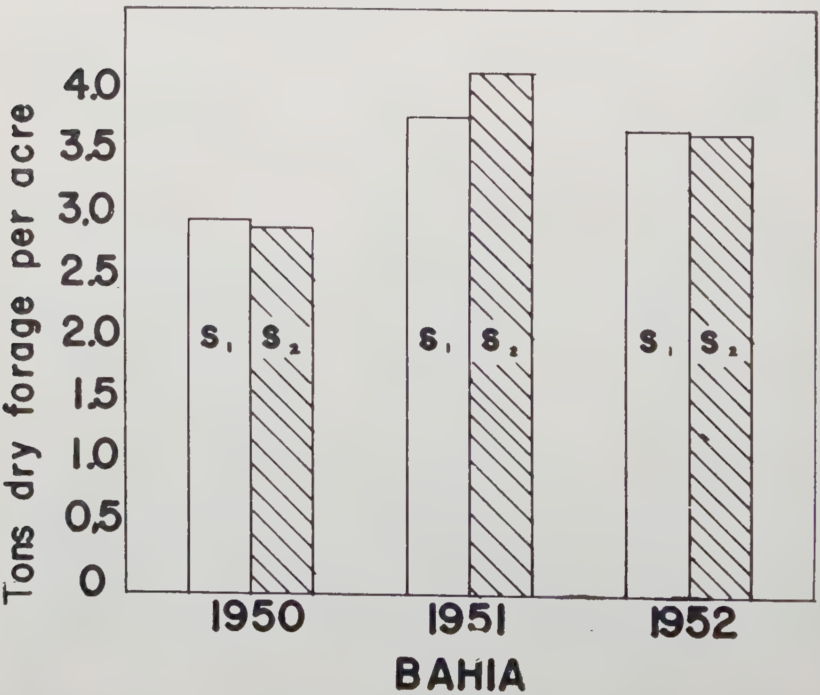

Figure 8.—Bar graph showing the production of Bahiagrass for each source of nitrogen for each year.

of each growing season and noting that the Harvests x PK level F-ratios are significant in 1951 and 1952 (Table 1), it can be assumed that after the first harvest the residual amount of potash from the higher (0-120-120) level of PK was not much larger than that from the lower level of PK. Furthermore, the means of individual harvests show that the 0-120-120 level was superior at the first harvest only. This confirms the assumption and leads one to conclude (as other workers have before) that potash should be applied throughout the growing season.

The 480 pound rate of nitrogen per acre per year would seem to be an enormous amount of nitrogen to add each year. However, when the curves in Figure 4 are examined, it can be seen that even at the 480 pound rate each pound of nitrogen was increasing yield by 20 pounds of dry forage. If it is assumed that nitrogen costs $0.10 per pound and dry forage costs $0.02 per pound, other costs being equal, the grower will receive $0.40 for each $0.10 invested. In addition, the nitrogen content (nitrogen analysis was conducted on some of the harvested plant material) of the highly fertilized plants was much higher than those receiving lower nitrogen rates.

It can be concluded from the significant Year x Rate, Year x Time and Year x Source interactions, that, for optimum nitrogen utilization, each year has a specific rate, source and time for applying it and that these change from year to year. The lack of significance of Source and Time in the combined analysis indicates that over the years these year-to-year variations would average out and become unimportant.

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RATES AND RATIOS OF NITROGEN, PHOSPHORUS, AND POTASSIUM FOR WHITE CLOVER AND PANGOLAGRASS ON REX FINE SAND

WILLIAM G. BLUE and NATHAN GAMMON, JR.*

A primary goal of soil fertility studies is the determination of fertilizer treatments and management practices which will produce maximum yields on a sustained basis. These data should be obtained under conditions which are as realistic as possible. In Florida, pasture studies should be made under grazing conditions, since this is the principle method of forage utilization.

Large differences between clipped and grazed pastures are possible. primarily because of the difference in nutrient removal. Animal excretion returns to the soil approximately 80 percent of the nutrients removed by grazing; whereas, none of the nutrients are returned to the soil when forage is harvested. Since the distribution of nutrients by grazing animals is not uniform, and high concentrations occur in localized areas, nutrient utilization by plants is probably less efficient than that where a uniform fertilizer application is made. In spite of this, the contribution of animal excrement to the fertility status of pasture soils is probably important. The expense involved in grazing studies with normal paddock-sized areas has been a serious limitation, yet data secured by techniques which do not involve grazing may lead to erroneous conclusions concerning both yield response and the fate of nutrients in the soil.

These experiments were conducted by a clipping-grazing technique, which was an attempt to approximate grazing conditions. Data are reported for the utilization of nitrogen, phosphorus, and potassium by Pangolagrass and Pangolagrass-white clover pastures as well as the nutrient status of the soil.

METHODS

Two experiments were conducted at Orange Heights, Florida, on Rex fine sand. This soil contains about two percent organic matter and has an exchange capacity of about 4 m.e. per 100 grams. It occurs on rolling to nearly level relief in northern Florida and is moderately well to somewhat poorly drained.

Experiment 1 was used to determine the quantities of phosphate and potash necessary for maximum white clover yields in a Pangolagrass-white clover pasture. Sufficient high-calcium lime was applied to maintain the reaction of the surface soil (0-6 inches) at pH 6.0 or slightly higher. Nine treatments were used in a randomized block design with four replications. These treatments were three rates of potash, each with

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* Assistant Biochemist and Soil Chemist, respectively, Soils Department, Florida Agricultural Experiment Station, Gainesville, Florida.

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three rates of phosphate, to give 1:3, 1:2, and 1:1 ratios.[1] Total quantities of nutrients applied are shown in Table 1.

TABLE 1.—PHOSPHATE - POTASH TREATMENTS, EXPERIMENT 1.

Ratios	P_2O_5 - K_2O Treatments Lbs./A.
1:3	20:60
1:2	30:60
1:1	60:60
1:3	40:120
1:2	60:120
1:1	120:120
1:3	60:180
1:2	90:180
1:1	180-180

The lowest potash treatments were made in October. The intermediate rates were applied in split application: one-half in October and one-half in January or February before the first harvest of clover. The highest potash treatments were also made in split application; one-third in October, one-third in January or February, and one-third in March following the first harvest of clover. During the first summer, approximately 50 pounds of nitrogen were applied following the clover; during the two subsequent summers no nitrogen was applied.

TABLE 2.—PHOSPHATE - POTASH TREATMENTS, EXPERIMENT 2.

Total Application—Lbs./A.	When Applied
(Pangolagrass-White Clover)	
400 lbs. 0-10-20	400 lbs., October
800 lbs. 0-10-20	400 lbs., October 400 lbs., January to February
1200 lbs. 0-10-20	400 lbs., October 400 lbs., January to February 400 lbs., March
(Pangolagrass)	
400 lbs. 0-10-20	400 lbs, March
800 lbs. 0-10-20	400 lbs, March 400 lbs., June
1200 lbs. 0-10-20	400 lbs, March 400 lbs., June 400 lbs., July to August

[1] All phosphate in both experiments was applied as single strength superphosphate and potash as muriate of potash.

Experiment 2 was set up to determine rates of nitrogen and of a phosphate-potash fertilizer for maximum yields from Pangolagrass and Pangolagrass-white clover pastures. A factorial design was used with three rates of nitrogen and three rates of fertilizer containing phosphate and potash. NH_4NO_3 and $NaNO_3$ were used as sources of nitrogen. The phosphate-potash treatments and times of application are shown in Table 2.

The nitrogen was applied periodically throughout the season at differential rates. The first increment of nitrogen for the Pangolagrass was applied in March and subsequent applications were made after each harvest during the summer. For the grass-clover pasture, the first nitrogen application was made after the last clover harvest; subsequent applications were made after each grass forage harvest. The nitrogen treatments are outlined in Table 3.

TABLE 3.—Nitrogen Treatments, Experiment 2.

1952		1954 and 1955	
Total Application Lbs./A.	When Applied	Total Application Lbs./A.	When Applied
(Pangolagrass-White Clover)			
None			
48	16 lbs. May 16 lbs. July 16 lbs. Sept.	72	24 lbs. May 24 lbs. July 24 lbs. Sept.
96	32 lbs. May 32 lbs. July 32 lbs. Sept.	144	48 lbs. May 48 lbs. July 48 lbs. Sept.
144	48 lbs. May 48 lbs. July 48 lbs. Sept.	216	72 lbs. May 72 lbs. July 72 lbs. Sept.
(Pangolagrass)			
None			
80	16 lbs. March 16 lbs. April 16 lbs. May 16 lbs. July 16 lbs. Sept.	96	24 lbs. March 24 lbs. May 24 lbs. July 24 lbs. Sept.
160	32 lbs. March 32 lbs. April 32 lbs. May 32 lbs. July 32 lbs. Sept.	192	48 lbs. March 48 lbs. May 48 lbs. July 48 lbs. Sept.
240	48 lbs. March 48 lbs. April 48 lbs. May 48 lbs. July 48 lbs. Sept.	288	72 lbs. March 72 lbs. May 72 lbs. July 72 lbs. Sept.

To avoid the artificial conditions resulting from clipping and forage removal, yields and forage samples were obtained by clipping a small portion of each plot. The forage was then spread on the clipped areas and the plots were intensively grazed until all forage was consumed. The plots were grazed simultaneously. Yields from these experiments are conservative because there was usually a lapse of one week between clipping and grazing, and refertilization.

Plant analyses were made from oven-dry material. Total nitrogen was determined by the Kjeldahl method and sulfur by the magnesium nitrate method(1). Solutions for the determination of potassium and phosphorus were prepared by dry-ashing one-gram samples at 450°C. The silica was dehydrated by adding 5N HCl and heating for one-half hour beyond dryness. The ash was then taken up in sufficient 5N HCl to give a final volume of 200 ml. of 0.1 N HCl.

Soil pH was determined by the Leeds-Northrop potentiometer using a thin-glass electrode. Extractable nutrients were determined from a 4:1 by weight, ammonium acetate (pH 4.8): soil, equilibrium extract.

Final portions of the analysis for plants and soils were the same. Phosphorus was determined colorimetrically, and potassium and sodium with the Model B Beckman flame spectrophotometer.

RESULTS AND DISCUSSION

The clipping-grazing system has been used previously, particularly in countries where intensive production is mandatory(6, 7, 8). One of the limitations of this system is that there is some transfer of nutrients between plots: this has the effect of increasing yields from low fertility treatments and of reducing yields from high fertility treatments. In these studies, the transfer of nutrients did not seem to be too serious.

For example, in experiment 2, the NH_4NO_3 and $NaNO_3$ treated plots were arranged side by side for each rate of nitrogen. Using Na as an indicator element and considering the highest nitrogen treatment, surface soil samples taken in October, 1954, contained 264 pounds of Na per acre from the $NaNO_3$ treated plots and only 16 pounds per acre from the NH_4NO_3 treatment. The difference in forage concentrations of Na from the two nitrogen-source treatments(4) substantiates the fact that the Na content of the soil from this treatment was low throughout the growing season. The soil content of potash also correlated well with potash treatments at the end of the 1954 season. Since the differential in Na and K concentrations in the soil were maintained, it is likely that other elements were similarly affected.

Phosphorus and Potassium

Data for Experiment 1 showing the effect of levels of phosphate and potash fertilization on white clover yields are shown in Table 4. Two harvests of clover were obtained each spring. Annual and three-year-average yields are shown. These data show a significant yield increase for phosphorus through 40 pounds per acre of P_2O_5. There was some yield response above 40 pounds but it was inconsistent and non-significant. Sixty pounds of potash appeared to have been nearly adequate, since yields were not significantly increased by higher rates. However, slightly

higher yields were consistently produced by 120 or 180 pounds of potash; this may indicate the need for some additional potash for maximum yields.

Data from Experiment 2 show that 80 pounds of potash per acre in a 1:2, phosphate: potash ratio was adequate for maximum yields of clover. Three rates of potash, 80, 160, and 240 pounds per acre in a 1:2 phosphate: potash ratio, were used. No significant increase in clover yields was obtained for these treatments. This quantity of potash also gave maximum yields of grass.

TABLE 4.—Average Yields of White Clover Forage Produced by Several Treatments in 1953, 1954, and 1955 and Average Yields for the Three Years from Experiment 1.

Treatments P_2O_5 - K_2O Lbs./Acre	Oven-dry Forage—Lbs./Acre			
	1953	1954	1955	3 Year Averages
20 - 60	1490	1390	1180	1320
30 - 60	1110	1490	1280	1290
60 - 60	1820	2000	2260	2030
40 - 120	2210	2450	2240	2300
60 - 120	1950	2260	2380	2200
120 - 120	2260	2640	2520	2470
60 - 180	2040	2480	2070	2200
90 - 180	1490	2540	2310	2110
180 - 180	1740	3160	2770	2560
LSD .01	740	1130	760	770
LSD .05	540	830	550	570

Using forage yields as the criterion, it may be concluded that approximately 40 pounds of phosphate and 80 pounds of potash per acre per year were adequate for maximum yields of white clover. Plant analytical data, Table 5, substantiate these conclusions. Plant phosphorus increased through the 40-pound rate of application. Plant potassium was significantly increased by 120 or 180 pounds of applied potash per acre over the 60-pound appplication. The fact that plant potash concentrations for the 60-pound rate of application were in the deficient range at the second harvest, according to previously published data(5), and that concentrations of potash were increased by the 120-pound rate lends credence to the conclusion drawn from the yield data that somewhat more potash was needed than was furnished by 60 pounds per acre.

Nitrogen data are included in Table 5. There was a tendency for higher concentrations with increasing amounts of applied phosphate at the first harvest and a significant increase at the second harvest. While nitrogen concentrations were correlated with the rate of phosphate fertilization, sulfur may also have been important. The increase in plant sulfur paralleled that of plant phosphorus; it has been shown that sulfur is necessary for maximum growth of clover on many of the sandy soils(9). Since sulfur is a component of protein, and definite correlation between plant nitrogen and sulfur has been obtained for Pangolagrass(2) it is probable that the correction of sulfur deficiency by increasing rates of

phosphate fertilizer was responsible for increasing concentrations of nitrogen. The increase in sulfur and nitrogen concentrations occurred only through the 40-pound application of phosphate.

TABLE 5.—Average Concentrations* of Nitrogen, Phosphorus, Potash, and Sulfur in White Clover.

Treatments P_2O_5 - K_2O Lbs./A.	First Cutting			Second Cutting			
	N—%	P—%	K—%	N—%	P—%	K—%	S—%
20 - 60	3.59	0.28	2.23	3 12	0.25	1.76	.19
30 - 60	3.65	0.29	2.58	3.01	0 27	2.05	.19
60 - 60	3.73	0.32	2.05	3 28	0.30	1.62	.22
40 - 120	3.94	0 33	2.88	3.31	0.30	2.49	.23
60 - 120	3.74	0.33	3.10	3.33	0.29	2.40	.22
120 - 120	3.84	0.40	3.16	3.35	0.33	2.28	.25
60 - 180	3.85	0.34	2.99	3.26	0.28	2 57	.25
90 - 180	3.76	0.33	3.00	3.27	0 30	2.93	.21
180 - 180	3.77	0.36	3.44	3.26	0.33	2.89	.23
LSD .05	N.S.	0.053	0.33	0.29	0.031	0.27	.035

* 3 year averages.

Response to Applied Nitrogen

Pangolagrass, Experiment 2

No significant differences between NH_4NO_3 and $NaNO_3$ for forage yields or plant nitrogen were obtained; therefore, data for the two nitrogen sources were averaged. Since no consistent yield differences were obtained for the phosphate-potash treatments these were used as replications in the statistical analysis for yields.

Forage yields and plant nitrogen concentrations are shown in Table 6. The over-all yield increase for nitrogen in 1952 was highly significant. Yield differences between each level of nitrogen approached significance at the 5 percent level; these increases were relatively uniform to the highest rate of nitrogen used (240 pounds per acre applied in five applications of 48 pounds each). The percentage of nitrogen in the forage generally increased with each rate of nitrogen, but the difference was least between the 160- and 240-pound rates.

During the winter and spring of 1952 and 1953 the stand of Pangolagrass was seriously depleted and no data are available for 1953. The grass was replanted during that summer.

For 1954, the no-nitrogen treatment was deleted and nitrogen rates were increased as indicated in Table 3. Four applications of nitrogen were made, totaling 96, 192, and 288 pounds per acre. Yield increases between each rate of nitrogen were approxmiately the same. The yield increase from nitrogen was highly significant; differences between each rate were significant at the 5 percent level. Plant nitrogen increased with each rate of nitrogen.

The 1955 yields generally were higher than in 1954. In contrast to previous years, however, there was no response to nitrogen at the rates

used. The percentage of nitrogen in the forage generally was increased: the largest increase was between 96 and 192 pounds of nitrogen.

TABLE 6.—RATES OF NITROGEN APPLIED, AND YIELDS AND PERCENTAGES OF NITROGEN IN PANGOLAGRASS FROM EXPERIMENT 2.

1952			1954			1955		
Nitrogen Applied Lbs./A.	Yield Lbs./A.	Plant Nitrogen %	Nitrogen Applied Lbs./A.	Yield Lbs./A.	Plant Nitrogen %	Nitrogen Applied Lbs./A.	Yield Lbs./A.	Plant Nitrogen %
May 22			May 11			April 22		
None	280							
32	710		24	1180	1.81	24	590	3 49
64	1200		48	810	1.95	48	300	3.49
96	1960		72	1470	1.97	72	320	3.78
July 22			July 15			July 19		
None	840	1.17	48	1330	1.43	48	2010	1.29
48	1340	0.98	96	1960	1.72	92	1930	1.53
96	1870	1.12	144	2720	1.81	144	2050	1.64
144	2440	1.22						
Aug. 27			Aug. 25			Aug. 23		
None	620	1.34	72	840	1.79	72	2890	1.23
64	1150	1 29	144	1150	2.16	144	2810	1.79
128	1500	1.58	216	1650	2.34	216	2890	1.83
192	1990	1.85						
Oct. 6			Oct. 6			Oct. 18		
None	150	1.26	96	2070	1.33	96	4620	0.95
80	430	1.34	192	3230	1.78	192	5330	1.27
160	430	1.76	288	4080	2.16	288	5550	1.48
240	520	1.75						
Total			Total			Total		
None	1880		96	5420		96	10060	
80	3640		192	7160		192	10350	
160	5010		288	9920		288	10830	
240	6910							
LSD*.05	2300			1280			N.S.	

* For Total Yields Only.

Pangolagrass and White Clover, Experiment 2

Yields and the nitrogen content of forages are shown in Table 7. The over-all yield increase for nitrogen was significant at the 5 percent level in 1952 and at the 1 percent level in 1954. Less nitrogen was applied than to Pangolagrass, but yields from treatments receiving the same quantity of nitrogen per application were higher than for the Pangolagrass alone. Considerable nitrogen was furnished to the grass by the clover, but not sufficient to preclude response to applied nitrogen.

Results for 1955 for the Pangolagrass-white clover pasture were essentially the same as for Pangolagrass alone. Yields were at least as high

as for 1954, but there was no response to applied nitrogen at the rates used. However, the nitrogen content of the grass generally was increased with each increment of nitrogen.

TABLE 7.—Rates of Nitrogen Applied, and Yields and Percentages of Nitrogen in Forage from Experiment 2.

1952			1954			1955		
Nitrogen Applied Lbs./A.	Yield Lbs./A.	Plant Nitrogen %	Nitrogen Applied Lbs./A.	Yield Lbs./A.	Plant Nitrogen %	Nitrogen Applied Lbs./A.	Yield Lbs./A.	Plant Nitrogen %
			(White Clover)					
April 1			April 5			April 21		
None	1100	3.63	None	760	3.92	None	770	3.59
None	950	3.46	None	640	4.08	None	950	3.82
None	1260	4.20	None	940	3.89	None	830	3.65
None	850	3.63						
May 22			May 11					
None	510	2.61	None	510	2.48			
None	400	2 38	None	590	2 34			
None	510	2.82	None	620	2.48			
None	500	2.61						
			(Pangolagrass)					
July 22			July 15			July 19		
None	1620	1.30	24	1890	1.56	24	2120	1.40
16	2140	1.01	48	2800	1.79	48	2480	1.46
32	2280	1.31	72	3240	2.02	72	1840	1.72
48	2850	1.35						
Aug. 27			Aug. 25			Aug. 23		
None	1290	1.43	48	1060	1.77	48	2870	1.43
32	1630	1.42	96	1660	2.14	96	3440	1.87
64	2440	1 65	144	1700	2.26	144	3130	1.92
96	2460	1.94						
Oct. 6			Oct. 6			Oct. 18		
None	410	1.25	72	2310	1.46	72	5060	0.97
48	690	1.51	144	4020	1.91	144	6210	1.33
96	900	1.69	216	4260	2.27	216	6010	1.52
144	1130	1.94						
Total			Total			Total		
None	4930		72	6530		72	10500	
48	5810		144	9140		144	13080	
96	7380		216	10760		216	11810	
144	7790							
LSD*.05	2300			2730			N.S.	

* For Total Yields only.

Continued study is needed to explain the lack of yield response in 1955 to the rates of nitrogen applied. It is also desirable to ascertain the frequency of occurrence of such periods. Analysis of soil profile samples in the fall of 1954 and spring of 1955 showed that a significant quantity of nitrate nitrogen was carried over from 1954. There was also a considerable quantity of nitrate nitrogen remaining in the surface soil at the end of the 1955 season, particularly in soil from the high nitrogen treatment, Table 8. These factors, probably the result of a dry 1954 season, plus the absence of intensive leaching rains in 1955, resulted in more efficient utilization of nitrogen in 1955 for all rates of application than in previous years, and were apparently sufficient to produce maximum yields, even at the low rate of nitrogen. The percentage of nitrogen recovered by plants from the Pangolagrass pasture, calculated on the basis of applied nitrogen, were 131, 77, and 66 for the 96-, 192-, and 288-pound rates, respectively. These recovery values are considerably higher than those reported by Volk(10) and Burton and DeVore(3), as obtained by the clipping method.

TABLE 8.—NITRATE NITROGEN IN SURFACE SOIL FROM THE THREE NITROGEN TREATMENTS IN EXPERIMENT 2 AS TAKEN FROM THE FIELD AND AFTER 18 DAYS INCUBATION.

Pangolagrass (Lbs./Acre)			Pangolagrass-White Clover (Lbs./Acre)		
Nitrogen Applied	NO_3-N in Soil 10/27/55	NO_3-N in Soil After 18 Days Incubation	Nitrogen Applied	NO_3-N in Soil 10/27/55	NO_3-N in Soil After 18 Days Incubation
96	14	19	72	14	26
192	10	27	144	16	33
288	40	51	216	40	51

Additional data are presented in Table 9 to further substantiate the belief that nitrogen carried over from 1954 and low leaching in 1955 were responsible for the lack of differential yield response. These data show that fall-applied nitrogen, on a Pangolagrass-clover pasture which had not been previously fertilized with nitrogen in 1955 and with only a low rate in 1954, gave highly significant yield increases through 100 pounds of nitrogen per acre. The percentage of plant nitrogen increased in a similar manner.

The conservation of other nutrients was also high for 1954. Extractable potash in the surface soil from the 80-, 160-, and 240-pound potash treatments from the Pangolagrass block, in October, 1954, averaged 116, 163, and 303 pounds per acre, respectively. These values are in contrast to a relatively uniform average of 66 pounds of potash at the end of the 1953 season during which no potash was applied. The potash content of grass forage from the NH_4NO_3 plots was consistently above 2 per cent in 1954 and 1955 for all potash treatments. Since yields ranged between 5,000 and 10,000 pounds of oven-dry forage per acre in 1954 and were

above 10,000 pounds per acre in 1955, it can readily be calculated that residual soil potash values of the magnitude obtained would have been impossible if the forage had been clipped and removed.

TABLE 9.—YIELD RESPONSE OF UNFERTILIZED PANGOLAGRASS FOLLOWING WHITE CLOVER TO FALL APPLIED NITROGEN.*

Pounds of N Applied per Acre	Lbs./Acre Oven-Dry	Percent Nitrogen
None	2470	0.88
25	3710	0.92
50	4130	1.17
100	5340	1.60
150	4880	1.39
LSD .01	1510	

* Nitrogen applied September 7, 1955.

The accumulation of large quantities of nutrients in sandy soils is not permanent. The equilibrium concentration of potash after leaching, while variable in different soils, is much lower than the values shown above. Plants also remove potash and other nutrients to even lower levels. However, these data indicate that nutrient carry-over, particularly where large quantities are applied under grazing conditions, may be significant in some seasons.

Seasonal Production

Economic utilization of forage produced under intensive systems in northern Florida necessitates very strict management practices. Though large amounts of forage can be produced, the bulk of production occurs between April and October. With the comparatively warm-season grasses used in permanent pastures, the season of production is quite independent of the rate of fertilization. Clover, which is valuable for several reasons, lengthens forage production at a critical period. But its direct contribution to total forage production, with heavy fertilization, is relatively small.

Factors which must be considered for the economic use of forage in an intensive fertilization program are (1) the rate of fertilization and amount of total pasture area to be fertilized; (2) the amount of forage which can be stored; and (3) the anticipated production of clover, and interim crops—particularly winter grazing crops—for grazing during periods of low production from permanent pastures. The production of forage is relatively expensive and, without efficient use can be unprofitable.

SUMMARY

Pangolagrass alone and Pangolagrass-white clover pastures on Rex fine sand were fertilized with several rates and ratios of phosphate and

potash, and with two sources and three or four rates of nitrogen. On the basis of three years data it was concluded that approximately 40 pounds of phosphate applied as 20 percent superphosphate and 80 pounds of potash (400 pounds of 0-10-20) were sufficient for maximum yields of white clover in a Pangolagrass sod and that this amount was also sufficient for maximum yields of grass even when fertilized with as much as 288 pounds of nitrogen.

A linear response of Pangolagrass to nitrogen up to 240 pounds per acre in 1952 and in 1954 to 288 pounds in 1954 was obtained. A similar yield response was obtained for Pangolagrass growing with clover. The nitrogen content of the grass forage increased also.

No yield response to nitrogen was obtained in 1955 (minimum rate 96 pounds of nitrogen per acre). The nitrogen content of forage was increased with increasing nitrogen levels. The lack of response was attributed, at least in part, to carry-over nitrogen and to low leaching in 1955, a year relatively devoid of intense rains. The efficiency of nitrogen utilization in 1955 was high compared to previous years. Relatively large amounts of potash, which corresponded to quantities applied, were found in the soil after the 1954 season.

The season of grass forage production was not appreciably altered by rates of fertilization. Some management practices necessary for the economic utilization of the large quantities of forage produced with intensive fertilization were enumerated.

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A SIMPLE METHOD OF ESTIMATING ECONOMIC OPTIMUM APPLICATIONS OF FERTILIZER

W. K. McPherson and Roy L. Lassiter, Jr.*

INTRODUCTION

Much of the research conducted by Agricultural Experiment Stations is designed to help farmers produce agricultural commodities more profitably. For a number of years after the Hatch Act was passed in 1887, the comparatively small staffs of the newly created Agricultural Experiment Stations concentrated their efforts on developing effective research programs. To help the Experiment Stations disseminate the results of their researches, the Congress passed the Smith-Lever Act establishing the Agricultural Extension Service in 1914. The work of this team of Agricultural Agencies was so successful that the local, state and federal governments steadily increased the amount of funds available for their use. By the middle of the twentieth century, The Experiment Stations and Extension Services in the several states were employing thousands of scientists and spending many millions of dollars annually.

Early in the life of the Experiment Stations and Extension Services, administrators found it necessary to organize their staffs into working units. Because scientists were becoming more highly specialized and because the Experiment Stations and Extension Services were an integral part of the Land Grant college system, the pattern of organization that gradually emerged was very similar to the academic organization used in the Colleges of Agriculture. Consequently, scientists working with similar subject matter were grouped together into organization units.

Organizations based on differences in the type of subject matter have been very successful in stimulating further specialization along the same lines. This was particularly true during the period in which scientists were developing the more general laws and relationships in the several fields of learning. However, as academic specialization progressed, gaps in the over-all body of knowledge began to appear. These gaps coincided with the border lines between the recognized fields of subject matter, e.g., between physics and chemistry, animal husbandry and nutrition, agronomy and soils. Similarly gaps between the several agricultural subject matter fields and political science, sociology, and economics appeared. Unless these gaps can be successfully bridged, serious deficiencies in research and extension programs can develop.

Dr. G. F. Warren, of Cornell University, is reported to have compared the border lines between the several academic fields to the hedge rows that separated many farm fields half a century ago. He observed that these hedge rows grew wider every year. Then, when farmers began to replace horses and mules with tractors, they dug out the hedge rows to

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* Professor of Agricultural Economics and Interim Instructor in Economics, respectively, University of Florida, Gainesville, Florida.

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make the fields larger. When farmers did this, they found that the land that had been in the hedge rows was almost always the most productive land on the farm. Dr. Warren was so convinced that the border line area between subject matter fields was a fruitful area for research that he began to work in the border line field between agronomy and economics. For this work, he won national acclaim as an agricultural scientist. Now the border line field that Dr. Warren helped develop is known as agricultural economics and has become so highly specialized itself that there are fertile fields for research along its border line with other subject matter fields.

Not all of the problems that lie in the border lines between the subject matter fields that are now used for administrative purposes can be resolved by combining and sub-dividing recognized fields. In many instances, the specialists themselves must assume the responsibility for integrating their work in the larger body of knowledge.

As scientists continue to specialize in more and narrower fields, those that can profit by the results of their research find it more and more difficult to apply the newly developed knowledge. Just as the family doctor seems to be disappearing from the American scene—so is the general agriculturist disappearang from American agriculture. In the general agriculturist, the farmers had a person that could council with them as they made the numerous and diverse decisions that all farmers should make for themselves. Now farmers must assemble information from numerous specialists and make their decisions without the counsel of a person that can help them evaluate all aspects of a situation. In an effort to help farmers cope with the task of assembling information from an increasingly large number of specialists, some of these specialists began to make specific recommendations—recommendations that farmers could accept in lieu of actually evaluating the facts and making independent decisions. At first, specialists confined themselves to making recommendations of the type that always made the farm enterprise more profitable and never less profitable. They recommended such things as the use of improved variety of corn that always yielded more than conventional varieties. Because the recommendations they made were so universally profitable, farmers shifted part of their responsibility for decision making to the specialists. In doing so, they surrendered part of the responsibilities that are vested in the entrepreneurs—the responsibilities to make management decisions. Thus surrendering a part of the responsibility for making decisions became a serious matter when farmers began to accept without question, recommendations for action that could seriously affect the profitability of farming. Recommendations to use specific amounts of fertilizers year in and year out without regard for changes in economic conditions fall into this category.

PURPOSE

The purpose of this paper is four-fold. The first is to identify the type of data needed to estimate economic optimum fertilizer applications. Second, a method of determining an economic optimum fertilizer applications is presented. Third, the relationships between physical and economic optimum fertilizer applications are examined. Finally, some of the con-

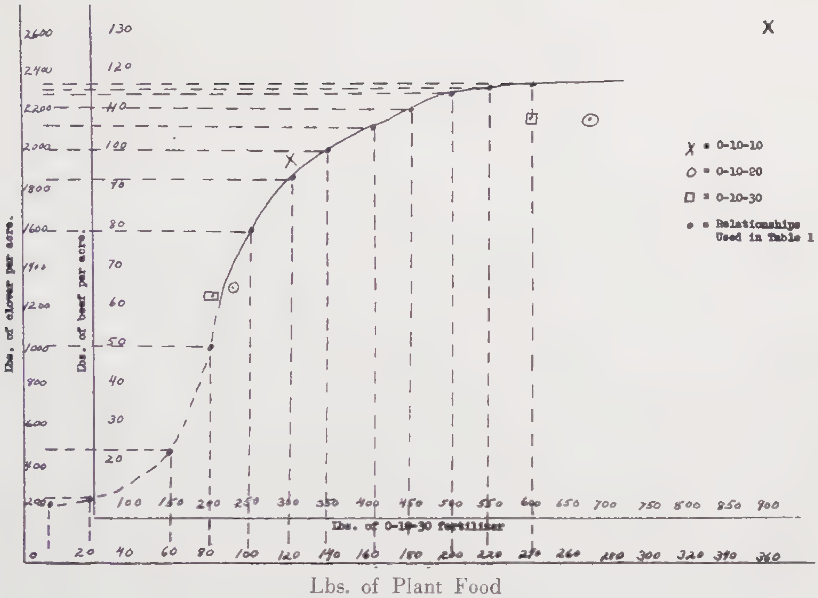

Figure 1.—Relationships between various applications of 0-10-30 fertilizer and yields of clover and beef per acre.[1]

[1] This production function was estimated from data collected by Dr. W. C. Blue, Florida Agricultural Experiment Station. Since three different fertilizer mixes were used in estimating this function, it is only an illustration and cannot be used to estimate the economic optimum fertilizer application in any particular situation.

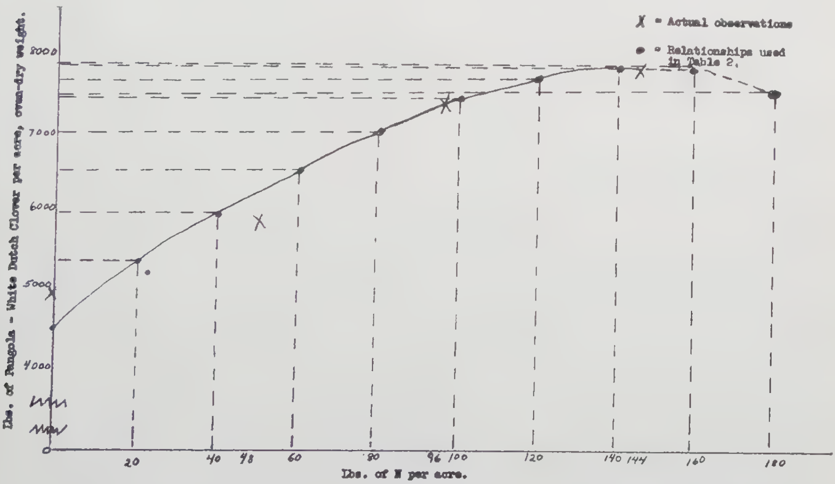

Figure 2.—Relationships between application of N and yields of Pangola and clover per acre.[1]

[1] This production function was estimated from data collected by Drs. W. C. Blue and Nathan Gammon, Florida Agricultural Experiment Station. Since the data covered only one year's experimental work, this production function is only an illustration and cannot be used to estimate the economic fertilizer application in any particular situation.

sequences of using fixed applications of fertilizer in different economic situations are evaluated.

DATA NEEDED TO DETERMINE ECONOMIC OPTIMUM FERTILIZER APPLICATIONS

The decision on how much fertilizer to apply to maximize income production of a specific crop on a specific type of soil is one that can be made quite independently of other farm management decisions. It is true, of course, that the need for making such a decision originates in the decisions that comprise both a farmer's long range and annual production plans, but the final decision on the specific amount of fertilizer to apply is one that can and should be delayed as long as possible. It is desirable to delay making this decision as long as possible because its accuracy depends upon the ability of the person making it to evaluate economic conditions some time in the future and economic predictions that are projected over the shortest possible period of time are most likely to be correct. It is especially desirable to delay making decisions on the amount of fertilizer to apply on pastures as long as possible because the economic optimum fertilization rate for grass and legumes varies so widely.

To establish the economic optimum rate of fertilization, it is necessary to have data on (1) the price of the fertilizer to be applied, (2) the amount that each incremental application of fertilizer will increase the yield of the product and (3) the price the product can be sold for after it is produced. The sources and characteristics of these data are analyzed separately.

The first factor—the price of the fertilizer to be applied—is the easiest to estimate. Current fertilizer price quotations can be obtained from farm supply stores and salesmen. To be entirely accurate the fertilizer price used in estimating economic optimum applications should include the cost of applying it. In illustrations that follow, it is assumed that the fertilizer prices used do include application costs. Fertilizer prices are the most definite figures that are used in deciding how much fertilizer can be profitably applied.

The second factor—the relationship between different fertilizer applications and crop yields—is estimated experimentally. Relationships between physical inputs and physical outputs of agricultural commodities are called production functions. Early in the twentieth century, Mitscherlich in Germany and Spillman in the United States discovered the characteristic pattern of production functions for crops by measuring crop yields obtained in response to different fertilizer applications.[1] Both of these scientists concerned themselves with the shape of the upper or diminishing returns segment of the functions. They concluded that, in this area, the equation for the functions were exponential, but they had somewhat different ideas on the form the expression should take. In fact, there are still differences of opinion between scientists as to the type

[1] D. B. Ibach and S. W. Mendum, *Determining the Profitable Use of Fertilizer*, U.S.D.A., B.A.E., F.M. 105 Mimeographed, June 1953.

0-10-30 Applied Lbs.	Yield: Oven-Dry Clover Lbs.	Yield: Total Beef* Lbs.	Yield: Marginal Beef Lbs.	Fertilizer Cost: Total** Dollars	Fertilizer Cost: Marginal Dollars	Beef Price Level, $10 per cwt.: Value of Marginal Beef Yield Dollars	$10 per cwt.: Net† Return Dollars	$20 per cwt.: Value of Marginal Beef Yield Dollars	$20 per cwt.: Net† Return Dollars	$30 percwt.: Value of Marginal Beef Yield Dollars	$30 percwt.: Net† Return Dollars
1	2	3	4	5	6	7	8	9	10	11	12
0	200	10.0		0			1.00		2.00		3.00
50	230	11.5	1.5	1.23	1.23	.15	—0 08	.30	1.07	.45	2.22
100	300	15.0	3.5	2.47	1.24	.35	—0.97	.70	0.53	1.05	2.03
150	450	22.5	7.5	3.71	1.24	.75	—1.46	1.50	0.79	2.25	3.04
200	1000	50.0	27.5	4.95	1.24	2.75	0.05	5.50	5.05	8.25	10.05
250	1600	80.0	30.0	6.18	1.23	3.00	1.82	6.00	9.82	9.00	17.82
300	1850	93.0	13.0	7.42	1.24	1.30	*1.88*	2.60	11.18	3.90	20.48
350	2000	100.0	7.0	8.66	1.24	.70	1.34	1.40	*11.34*	2.10	21.34
400	2100	105.0	5.0	9.90	1.24	.50	0.60	1.00	11.10	1.50	*21.60*
450	2180	109.0	4.0	11.13	1.23	.40	—0.23	.80	10.67	1.20	21.57
500	2250	112.5	3.5	12.37	1.24	.35	—1.12	.70	10.13	1.05	21.38
550	2280	114.0	1.5	13.61	1.24	.15	—2.21	.30	9.19	.45	20.59
600	2300	115.0	1.0	14.85	1.24	.10	—3.35	.20	8.15	.30	19.65

* The conversion factor of 20 lbs. of oven-dry clover equals 1 lb. of beef was estimated by Drs W. G. Blue and T. J. Cunha.
** Price of 0-10-30 is $49.50 per ton—estimated by Johnson Bros. Feed Co., Gainesville, Florida.
† Net returns above fertilizer costs (see text).
Source—See Figure 1.

TABLE 2.– PANGOLA-CLOVER YIELDS, TOTAL AND MARGINAL BEEF YIELDS, TOTAL AND MARGINAL FERTILIZER COSTS, MARGINAL AND NET VALUE OF BEEF AT THREE PRICE LEVELS FOR VARIOUS APPLICATIONS OF NITROGEN.

N* per Acre Lbs.	Yield			Fertilizer Cost		Beef Price Level					
						$10 per cwt.		$20 per cwt.		$30 per cwt.	
	Pangola-Clover Oven-Dry Lbs.	Total Beef** Lbs.	Marginal Beef Lbs.	Total† Dollars	Marginal Dollars	Value of Marginal Beef Yield Dollars	Net‡ Return Dollars	Value of Marginal Beef Yield Dollars	Net‡ Return Dollars	Value of Marginal Beef Yield Dollars	Net‡ Return Dollars
1	2	3	4	5	6	7	8	9	10	11	12
0	4500	225		8.10			14.40		36.90		59.40
20	5350	268	43	11.22	3.12	4.30	15.58	8.60	42.38	12.90	69.18
40	5950	298	30	14.34	3.12	3.00	15.46	6.00	45.26	9.00	75.06
60	6500	325	27	17.46	3.12	2.70	15.04	5.40	47.54	8.10	80.04
80	7000	350	25	20.58	3.12	2.50	14.42	5.00	49.42	7.50	84.42
100	7400	370	20	23.70	3.12	2.00	13.30	4.00	50.30	6.00	87.30
120	7700	385	15	26.82	3.12	1.50	11.68	3.00	50.18	4.50	88.68
140	7800	390	5	29.94	3.12	0 50	9.06	1.00	48.06	1.50	87.06
160	7800	390	0	33.06	3.12	0	5.94	0	44.94	0	83.94
180	7500	375	—15	36.18	3.12	—1.50	1.32	—3.00	38.82	—4.50	76.32

* In addition to base application of 400 lbs. of 0-10-20 per acre.
** The conversion factor of 20 lbs. of oven-dry clover equals 1 lb. of beef was estimated by Drs. W. G. Blue and T. J. Cunha.
† Cost of 400 lbs. of 0-10-20 fertilizer at $40.50 per ton plus the cost of the indicated amount of Nitrogen in the form of NH_4NO_3 at $100 per ton.
‡ Net returns over fertilizer costs.
Source—See Figure 2.

of equations that best describe production functions.[2] Likewise, scientists are still trying to find out whether or not the lower or increasing returns end of the functions are linear or curvilinear in a manner that, when this segment added to the diminishing returns segment, the total curve is similar to the conventional sigmoid growth curve. Fortunately, it is not necessary to resolve these academic questions to establish the relationship that exists between the physical production and the point of maximum economic returns. In fact, after working out his physical production function equation, Spillman became interested in its economic aspects and, along with Dr. Warren, was one of the pioneers in developing the border line field between economics and agronomy.

Experiments designed to produce this type of data are conducted by Agricultural Experiment Stations. Farmers need to know the relationship between a wide variety of fertilizer applications and crop yields to estimate the optimum amount of fertilizer to use under a wide variety of economic situations. An example of a production function of sufficient range to facilitate decision making is shown in graphic form in Figures 1 and 2 and tabular form in Tables 1 and 2. Since the actual observations in the experiment used in Figure 1 and Table 1 did not cover the entire range that is most desirable, the lower end of the curve was extrapolated to show what the lower or increasing returns end of the curve might have looked. Crop yields corresponding to uniform incremental applications of fertilizer were estimated from free hand curves fitted to experiment data. The round dots on Figures 1 and 2 correspond to the incremental applications of fertilizer in Tables 1 and 2. Making estimates of crop yields resulting from the use of applications of fertilizer that increase by uniform amounts is a necessary requisite for making simple estimates of economic optimum fertilizer applications.

Agronomists and soil scientists can facilitate the use of their fertilizer response research in three ways:

A. They can include a wide enough range of fertilizer applications in their experiments to obtain data that will describe the entire production function rather than a narrow segment of it. If this is not feasible, the range of experimental application can be made sufficiently wide to discover and describe the diminishing returns segment of the function.

B. The production function can be described either graphically or by an equation. Only the graphic method of describing the function is presented here since it facilitates the use of this type of data in decision making. Describing the function with an equation is more precise and useful to scientists in the solution of more complex problems but it involves the use of more advanced mathematical techniques—the calculus.

C. The crop yield responses that can be expected from the application of uniform increments of fertilizer can be effectively presented in tabular form (see the first 4 columns of Tables 1 and 2). Presenting fertilizer crop yield responses in this way facilitates the calculation of marginal costs and marginal returns under different economic conditions, and hence the estimation of the economic optimum applications.

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[2] D. B. Ibach and S. W. Mendum, *Ibid.*, also Paul R. Johnson, *Alternative Functions for Analyzing a Fertilizer Yield Relationship*, Journal of Farm Economics, Vol. 35, Nov. 1953, p. 519, and Earl O. Heady, *Economics of Agricultural Production and Resource Use*, Prentice Hall, New York, 1952, pp. 52-89.

The third factor—the price of the product after it is produced is difficult to estimate because economic conditions and hence prices can change rapidly. It is the change in price that takes place between the time crops are planted and the time they are harvested and sold that injects considerable risk into the business of farming. However, profits are the rewards for assuming risks and if farmers expect to earn profits, they must assume the risk of estimating the price of agricultural products in the future.

A SIMPLE METHOD OF ESTIMATING THE ECONOMIC OPTIMUM FERTILIZER APPLICATION

The economic optimum fertilizer application is the application that will enable farmers to maximize profits or minimize losses. This economic optimum is attained when the cost of the last increment of fertilizer just equals the value of the increase in the crop yield due to the application of that increment. To be mathematically precise, this incremental application of fertilizer must be infinitesimally small and a precise estimate of the size of the total fertilizer application corresponding to the economic optimum increment could be made by integrating a relatively simple differential equation. In practice, however, it is not necssary to be mathematically precise and the economic optimum fertilizer can be estimated from finite incremental fertilizer applications and the use of simple arithmetic. With the data described in the preceding section of this paper, it is a relatively easy task to estimate the size or rate of the economic optimum fertilizer application with all the accuracy needed in commercial farming operations. This is especially true if the experimental data are available in the form illustrated in columns 1, 2, 3, and 4 of Tables 1 and 2. This kind of data is needed by ranchers and farmers desiring to compute economic optimum applications of fertilizer. Here it is important to note that, while the data used in this paper were taken from actual experiments, they are not sufficiently reliable for farmers to use. This is because (a) one of the series of data used covers only a one-year period, and (b) it was necessary to extrapolate the other curve to make it illustrative.

The first step in making a useful estimate of the economic optimum fertilizer application is to be sure the data relating yields to fertilizer application rates is applicable to the particular soil types used and crop grown. Because the number of soil types, fertilizer mixes and crops produced in Florida is so large, it will be a long time before data needed to calculate optimum fertilizer applications under all economic conditions are available. On the other hand, responses to the application of fertilizer to some soil types are so similar that the same function can be used. Until a considerable number of production functions are established, farmers will not be able to estimate the correct amount of fertilizer to use under any economic situation with very much precision.

The second step in estimating the econmic optimum fertilizer application is to determine the cost of the entire series of fertilizer applications and the cost of each incremental application. The cost of a fertilizer application of any particular size is determined by multiplying the cost of a ton of fertilizer by the fraction of a ton corresponding to the size of the application. For example, an application of 150 lbs. of fertilizer

costing \$49.50 per ton is \$49.50 x 150/2000, or \$3.71. Thus, the cost of each application of fertilizer from 50 to 600 pounds can be easily estimated. This was done to obtain the data appearing in column 5 of Tables 1 and 2. When the size of the incremental application is held constant, the task of computing the cost of the last increment of each application is relatively simple. For example, in Table 1 Column 6, 50 lbs. of fertilizer was the same in every instance, i.e., 50/2000 x \$49.50 = \$1.23+.

The third step in calculating the economic optimum fertilizer application is somewhat more difficult, principally because it involves the use of an estimate of the price at which the product can be sold *after* it is produced. It is very difficult to estimate the price of agricultural products several months in the future, but once these estimates are made it is comparatively easy to estimate the optimum size of the fertilizer application.

The value of the added product associated with the addition of each increment of fertilizer is estimated by multiplying the marginal product (Table 1. Column 4) by the estimated price of the product. For example, in Table 1, the first 50 lb. application of fertilizer is associated with an increase in beef yield of 1.5 lbs. which—at \$10 per cwt.—equals 15 cents as shown in Column 7. The value of the incremental or marginal product for each incremental or marginal application of fertilizer is calculated in the same manner. These are all the calculations that are necessary to estimate the economic optimum fertilizer application, but many farmers also want to estimate the net value of the product over fertilizer costs before deciding how much fertilizer to use. These net returns are easily calculated by multiplying the total product in pounds (column 3) by the estimated price of the product per pound and subtracting the cost of the fertilizer. Thus, the value of 11.5 pounds of beef produced when 50 pounds of fertilizer was added had a value of 11.5 x .10, or \$1.15. The gross value of the product—\$1.15—minus the cost of the fertilizer—\$1.23—equals a net return of minus 8 cents (see Table 1, column 8). In other words, for this particular application, the fertilizer cost 8 cents more than the total value of the product. On the other hand, when 300 pounds of fertilizer was added, the total value of the product exceeded the value cost of the fertilizer by \$1.88 (again, see Table 1, column 8).

The last step in estimating the economic optimum fertilizer application can be accomplished in two ways. One method consists of using the relationships stated in the first sentence of this section; i.e., that the economic optimum application is the application of which the cost of the last increment (or marginal cost of fertilizer) is just equal to the value of the product added by the last application. Using the data presented in Table 1, it is clear that when 150 pounds of fertilizer is applied, the last 50 pounds does not increase the yield enough to pay for the fertilizer. When the price of beef is \$10 per cwt., the last 50 pounds of fertilizer cost \$1.24, but produces only 7.5 pounds of beef, or a return of 75 cents. However, the next 50 pounds of fertilizer applied stimulated an increase in the yield of beef of 27.5 which, at 10 cents per pound, was worth \$2.75—substantially more than the marginal fertilizer cost of \$1.24. At this point, the marginal product is worth more than the marginal cost, but the economic optimum is not reached until the value of the marginal

product again equals to its marginal cost. This occurs when the total fertilizer application is increased from 300 pounds to 350 pounds. At 300 pounds the marginal product is 13 pounds of beef, which at 10 cents per pound, is worth slightly more than the marginal cost—the cost of the last 50 pounds of fertilizer, or $1.24. By increasing the fertilizer application by another 50 pounds to a total of 350 pounds, the marginal product is only 7 pounds of beef, which, at 10 cents per pound, is worth only 70 cents—substantially less than the cost of the 50 pounds of fertilizer used to obtain this increase. Hence the economic optimum is estimated as being 300 pounds of 0-10-30 fertilizer, or the amount corresponding to the point where the marginal cost of the fertilizer applied approximately equals the marginal value of the product. Here it is important to note that the economic optimum occurs in the diminishing returns segments of the production function. However, farmers may also want to know the marginal and net returns for fertilizer applications in the increasing returns segment of the function, although it is not essential to making rational decisions.[3]

Another method of estimating the economic optimum fertilizer application in any economic situation is to select the fertilizer applications that produce the highest net returns (see Columns 8, 10 and 12 of Tables 1 and 2). This method of estimating economic optimum fertilizer application provides an excellent starting point for estimating net income from an enterprise, but net income over fertilizer costs is not the net income from the enterprise. To estimate the latter, all costs must be subtracted from gross returns. However, the amount of other costs do not affect the economic optimum fertilizer application if other costs were incurred prior to the time the fertilizer was applied. If the costs previously incurred were so high that the enterprise will incur a loss—the loss can be minimized by applying economic optimum applications of fertilizer just as net incomes can be maximized. In a given economic situation, the economic optimum fertilizer application is the same regardless of the method used to estimate it. Consequently, calculating net returns provides a simple and informative method of checking estimates of the size of the economic optimum application made by equalizing marginal costs with marginal returns.

RELATIONSHIPS BETWEEN PHYSICAL OPTIMUM AND ECONOMIC FERTILIZER APPLICATIONS

There are two physical optimum fertilizer applications (1) the application that results in the largest physical product [600 lbs. of 0-10-30 in the first illustration (see Table 1 and Figure 1) and 400 lbs. of 0-10-20 with 140 lbs. of N in the second (see Table 2 and Figure 2)] and (2) the application, the last increment of which results in the greatest increase in physical output (250 lbs, in the first illustration and 20 lbs. in the second). The physical optimum application varies with such things as kind and amount of fertilizer, moisture conditions, soil types, etc., but is the same in all economic situations.

[3] Data on the increasing returns segment of the function may be particularly useful to farmers that have limited capital resources and hence must ration this capital in such a manner that will enable them to obtain the optimum income from a combination of several enterprises rather than to maximize the income from only one.

In contrast, the economic optimum fertilizer application varies with economic conditions in general and cost-price relationships in particular. In the first illustration, the economic optimum fertilizer application changes from 300 lbs. of 0-10-30 when beef sells for $10 per cwt. to 350 lbs. when beef is worth $20 per cwt. and 400 lbs. when beef is worth $40 per cwt. The change is more pronounced in the second example where the economic optimum shifts from 20 lbs. of N when the price of beef is $10 per cwt. to 100 lbs. of N when beef sells for $20 per cwt. to 120 lbs. when the price of beef rises to $30 per cwt.

Because of the economic optimum application of fertilizer changes with economic conditions, farmers must estimate them for themselves. Just before the fertilizer is applied farmers must estimate the prices the product will sell for and, on the basis of this estimate and the cost of fertilizer, determine the size of the optimum application. The importance of making these estimates correctly is most clearly shown in the second example. By using the economic optimum fertilizer application for $30 beef when beef actually sells for $10 a farmer can either increase losses or decrease profits by about $4 per acre. Or, by using the economic optimum fertilizer application for $10 beef when the price of beef is $30 per cwt. he reduces profits or increases losses by approximately $20 per acre. When differences between economic optimum fertilizer applications under different price expectations can affect net income of a farm enterprise by $20 an acre, they can easily account for the differences between profit and loss.

SUMMARY AND CONCLUSIONS

Farmers need only three types of data to make estimates of the economic optimum applications of fertilizer. These are: (a) the price of fertilizer including the cost of application, (b) the physical relationship between the amount of fertilizer applied and increases in crop yields and (c) estimates of the prices the product can be sold for after it is produced. Researchers can facilitate the use of fertilizer—crop yield relationship data by (a) extending the experimental work to include at least the entire upper segment of the production function from the point at which crop yields increase at a decreasing rate, and as many of the increasing returns relationships as possible (b) estimating the crop yield responses for uniform increments of fertilizer applied and (c) publishing experimental data in terms of the crop yield responses to fertilizer applications that differ by constant amounts.

Economic optimum fertilizer applications can be estimated on the basis of simple arithmetic calculations with sufficient accuracy to use in making farm management decisions. Two illustrations are used to show (a) how the calculations are made and (b) the relationship between physical and economic optimum fertilizer applications between economic optimum fertilizer applications in different economic conditions.

Failure to take the economic situation into consideration in making decisions on how much fertilizer to apply can easily account for the difference between profitable and unprofitable farm enterprise.

Farmers that use the same application of fertilizer year after year just because someone recommended it are (a) surrendering their entrepreneural responsibility for making decisions to others and (b) contribut-

ing to inflexibility in the production of agricultural commodities by not varying supply in response to changing economic conditions. By not adjusting the amount of agricultural commodities produced to changes in economic conditions, farmers help to create the recurring situation in which agricultural prices rise higher and fall lower than the prices of other commodities. Or stating the proposition in quite another way, agricultural scientists who induce farmers to use the same amount of fertilizer without regard for changes in economic conditions are, partly, responsible for creating instability in farm prices.

RESPONSE OF WARM-SEASON PERMANENT-PASTURE GRASSES TO HIGH LEVELS OF NITROGEN

R. L. Jeffers *

INTRODUCTION

Difficulty in maintaining vigorous stands of drought-resistant legumes in summer pasture mixtures in the Southeast has resulted in the universal use of nitrogen fertilizer as a source of nitrogen to the growing forage, and indirectly as a source of protein to the grazing animal. Recent reports in the literature indicate economical yield responses have been made at much higher levels of nitrogen fertilization than has been used in the past(1, 2, 3, 4, 5). For this reason, the response of warm-season permanent-pasture grasses to high levels of nitrogen has been of extreme interest to the forage and pasture worker in this region.

There has been widespread acceptance and use of such improved grasses as Pensacola Bahia, Coastal Bermuda, and Argentine Bahia in the Northwest Florida area. This points up a need for study of the factors mentioned above under the climatic conditions which prevail in this area.

Small plot studies were initiated in the fall of 1952 to study the response of these grasses to various levels of nitrogen. In the spring of 1955, the study was expanded to determine the response of summer grasses to high levels of nitrogen under grazing conditions. The first year's results on the latter study are reported in this paper.

EXPERIMENTAL METHODS

Small Plot Studies—1952-55

A split-plot design, replicated four times, was employed to evaluate the nitrogen response by Pensacola Bahia, Coastal Bermuda, and Argentine Bahia. These grasses were established as the main plots on a Red Bay fine sandy loam soil; the nitrogen levels constituted the sub-plots. The following nitrogen levels were studied in 1954 and 1955:

TABLE 1.—Nitrogen Treatments.

Treatment	1954	1955
1	Crimson Clover	Crimson Clover
2	34	50
3	68	100
4	125	200
5	250	400
6	500	800

* Associate Agronomist, West Florida Experiment Station.
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Nitrogen was applied as ammonium nitrate in four applications at approximately 45-day intervals, except for the low rates (34, 50, and 68 pound levels), which were applied in two applications. The initial application of nitrogen was applied during the first week in March.

The following fertilizer applications were made: At the time of seeding, the experimental area was treated with one ton of dolomitic limestone, and the P_2O_5 and K_2O were applied at the rate of 0-100-100 per acre. In the 1953 growing period, the grasses were treated uniformly with a 40-140-140 rate to assure a good establishment of stand. In March 1954, an application of 0-106-106 was made; and one ton of dolomitic limestone was applied in the fall. Plot fertilization in 1955 was balanced to the ratio of 2-1-1 for N-P_2O_5-K_2O. The amounts of P_2O_5 and K_2O, of course, depended on the particular nitrogen level in a plot.

The forage yields reported herein were from four cuttings in 1954 (April 8, April 27, June 25, and August 9) and four in 1955 (May 24, July 11, August 26, and November 3) and, unless otherwise noted, are reported as tons of oven-dry material per acre.

In January 1955, the experiment was expanded to study the response of summer grasses to high levels of nitrogen on similar heavy textured soils under actual grazing conditions. Unreplicated plots of established pastures of Pensacola Bahia, Coastal Bermuda, and Argentine Bahia, 3.75 acres in size, were sprayed with a mixture of 2-4-D and 2-4-5-T. The rate used was two pounds actual material per acre. This was done to remove all remnants of a previous clover stand. Starting in March, 1.25 acre paddocks in each pasture block received 100, 200 and 400 pounds of nitrogen as ammonium nitrate in four applications at approximately 45-day intervals. The N, P_2O_5, and K_2O levels were maintained in a 2-1-1 ratio for all treatments.

Beef yields were obtained with yearling steers using the "put and take system" in stocking the pasture for maximum utilization of the forage produced. Beef yields are reported as pounds of beef gain per acre.

EXPERIMENTAL RESULTS

Response of Individual Grasses to Nitrogen

The data in Tables 2 and 3 show the response of Pensacola Bahia, Coastal Bermuda and Argentine Bahia to six different nitrogen treatments in 1954 and 1955, as measured in tons of dry forage produced per acre. For both years, Pensacola Bahia produced more dry forage as averaged over all nitrogen levels than either Coastal Bermuda or Argentine Bahia. In 1954, which was unusually dry, these differences were highly significant; while in 1955, an extremely favorable year for moisture, the superiority of Pensacola Bahia was barely significant at the five percent level. Although Coastal Bermuda was slightly better than Argentine Bahia in 1954, the three grasses did not differ materially in over-all response to nitrogen in 1955.

When response comparisons between grasses are made, within each nitrogen level, the data show that Pensacola Bahia produced more dry forage at each nitrogen level in 1954, except the clover treatment. In 1955, on the other hand, there were no differences between any of the grasses up to the 400-pound level of nitrogen. But at the 400 and 800

pounds levels both Pensacola and Argentine Bahia responded more markedly to higher levels of nitrogen than did Coastal Bermuda. This can be partially explained on a late spring freeze which had more effect on Coastal Bermuda than the Bahia grasses. Unreported data in 1955 has shown that Argentine Bahia has a far greater capacity to produce in the mid-summer period when good growing conditions prevail. This probably accounts for the fact its performance was not significantly different than that of Pensacola Bahia in 1955.

TABLE 2.—Total Yield of Oven Dry Forage, in Tons per Acre, Produced in 1954.

Grass Species	Annual Rates of Nitrogen						
	Clover	34	68	125	250	500	Average
Pensacola Bahia ..	2.01	1.30	1.92	2.98	4.97	7.30	3.41
Argentine Bahia ..	1.70	0.62	0.92	1.96	3.10	5.99	2.38
Coastal Bermuda ..	1.85	0.85	1.27	2.50	3.93	5.66	2.68
Average	1.85	0.92	1.37	2.48	4.00	6.32	

Least Significant Differences:	0.05	0.01
1—Between grasses over all nitrogen rates	0.27	0.41
2—Between nitrogen rates over all grasses	0.22	0.30
3—Between nitrogen rates within same grass	0.41	0.61
4—Between grasses within same nitrogen rate	0.44	0.61
	C.V.	10.2%

TABLE 3.—Total Yield of Oven-Dry Forage, in Tons per Acre, Produced in 1955.

Grass Species	Annual Rates of Nitrogen						
	Clover	50	100	200	400	800	Average
Pensacola Bahia ..	2.57	1.91	2.55	4.53	7.47	10.27	4.88
Argentine Bahia ..	2.10	1.31	2.13	4.06	6.86	9.50	4.33
Coastal Bermuda ..	2.27	1.69	2.33	4.00	6.32	8.57	4.20
Average	2.31	1.64	2.34	4.20	6.88	9.45	

Least Significant Differences:	0.05	0.01
1—Between grasses over all nitrogen rates	0.60	N.S.
2—Between nitrogen rates over all grasses	0.45	0.60
3—Between nitrogen rates within same grass	0.83	1.17
4—Between grasses within same nitrogen rate	0.92	1.30
	C.V.	13.2%

Overall Response to Nitrogen by Grasses

The data in Tables 2 and 3 further reveal there was a positive yield response both years to increasingly higher nitrogen levels, up to the maximum level, as averaged overall grass species. These differences were highly significant each year. The data in Table 4 show the relative efficiency of nitrogen for each treatment level and relative efficiency of increased increments of nitrogen in producing dry forage by the three summer grasses under test.

The data in Table 4 indicate the most efficient use of nitrogen in 1954 and 1955 for a particular nitrogen level, based on pounds of dry forage per pound of nitrogen applied, was at the lowest nitrogen level. Above the lowest treatment level, the efficiency of nitrogen use decreased progressively as the amount of nitrogen applied increased to the highest level. The data are almost identical both years (see Column 3, Table 4).

TABLE 4.—The Relative Efficiency of Several Nitrogen Rates on the Production of Oven-Dry Forage by Three Summer Grasses in 1954 and 1955.

Pounds of* N per Acre per Year	1954 Pounds of Dry Forage per Acre: Season Total	Per Pound of N	Due to Each Increment of N	Per Pound of Increment N	Net Worth of** Dry Forage per Pound of Increment N
34	1840	61.0			
68	2740	40.3	900	26.5	.40
125	4960	39.7	2200	34.7	.52
250	8000	32.0	3040	24 3	.36
500	12640	25.0	4640	18.6	.28
	1955				
50	3280	66.0			
100	4660	47.0	1380	27.6	.41
200	8400	42.0	3740	37.4	.56
400	13700	34.0	5360	26.8	.40
800	18900	24.0	5140	12.8	.19

* As Ammonium Nitrate.
** Based on average quality at $30.00 per ton as compared to N at 10.8 cents/lb.

The yield of dry forage per acre for each increment of nitrogen applied over the previous increment is of special importance (see Column 4). In 1954 there was a positive yield response for each increment of nitrogen up to the 500-pound treatment level. But for 1955, an increase was obtained only up to the 400-pound treatment level. The yield resulting from the 400-pound increment of nitrogen (i.e. the actual forage produced by the nitrogen increment between 400- and 800-pound levels) was less than the amount obtained from the previous 200-pound increment. Thus, under this experiment, the increment response to nitrogen became negative, or reached the law of diminishing return, somewhere between the 400- and 800-pound level.

The dry forage produced per pound of nitrogen expended for each increment is shown in Column 5, Table 4. These figures indicate the relative efficiency of nitrogen between each increment of nitrogen. In 1954, the 68-pound increment (125-pound treatment level) was the most efficient nitrogen applied. For each pound of nitrogen, 34.7 pounds of dry forage was produced. In 1955, the 100-pound increment (200-pound treatment level) was most efficient.

TABLE 5.—Three-Year Summary of Grazing Trials of Summer Grass Using a Clover Mixture as the Only Source of Nitrogen. Data in Pounds Beef Gain per Acre.

Pasture Mixture	1952	1953	1954	Average
Pensacola Bahia-Clover*	468	361	703	511
Argentine Bahia-Clover	389	338	487	405
Coastal Bermuda-Clover	457	430	559	482
Average	438	376	583	463

* Clover Mixture—Red Clover, Ladino Clover and Crimson Clover.
Fertilizer: 500 pounds of 0-14-14/acre/year; cost: $7.50.

Value of Crimson Clover as Nitrogen

Although this study was principally designed to study the nitrogen response from commercial nitrogen, a treatment was provided to estimate the value of clover as a nitrogen source. The value of clover as a nitrogen source when grown in association with each of the summer grasses is shown in Tables 2 and 3. The results indicate it was equal to about 100 pounds of nitrogen in both 1954 and 1955.

Response to Nitrogen Under Grazing Conditions

The extraordinary response to high levels of nitrogen by Pensacola Bahia, Coastal Bermuda and Argentine Bahia grasses in the small plot studies (Tables 2 and 3) resulted in expanding the study to include a grazing experiment in 1955. Since the cattle return much of the nitrogen to the soil through urine and droppings, nitrogen levels of 100, 200, and 400 pounds were selected for this study. The data in Table 6 show the results of the first year's study.

These data show that, when averaged over all nitrogen levels, the greatest response was made by Pensacola Bahia. This was evident for every nitrogen level. Argentine Bahia was intermediate and Coastal Bermuda was least in response. Coastal Bermuda did not recover sufficiently following the August 15 application of nitrogen to justify further grazing that season.

The average response of the grasses to the nitrogen levels is noteworthy and appears in Table 6. The beef gains recorded show a range from 474 pounds gain at the 100 pound level, to 563 pounds gain at the 400-pound level. The data would indicate a spread of only about 100

pounds of beef between the lowest and highest levels of nitrogen. There was only 150 pounds difference between these levels for the highest responding grass under test.

TABLE 6.—Response in 1955 by Three Summer Grasses to Different Rates of Nitrogen. Data in Pounds Beef Gain per Acre.

Pasture Species	Annual Rates of N			
	100	200	400	Average
Pensacola Bahia	516	576	668	570
Argentine Bahia	500	566	608	558
Coastal Bermuda*	406	429	412	416
Average	474	524	563	515

Fertilizer (2-1-1 Ratio)	100-50-50	200 100-100	400-200-200
Fertilizer Cost**	$16.05	$32.10	$64.20
Gain Needed at 16c Pound	100	200	400
Gain Needed to Justify 2-1-1 Ratio Over Clover on Clover Land	513	613	813

* Recovery growth after August 15 not sufficient for grazing.
** Based on ammonium nitrate at $72.00/ton and 0-14-14 at $30.00/ton.

A summary of three years results of grazing the pasture blocks listed in Table 6, when the nitrogen source was a mixture of clovers, is reproduced in Table 5. The average annual production of beef gain per acre obtained over the three-year period of varying climatic conditions with clover furnishing the nitrogen was approximately 463 pounds. This is in contrast to the average figure of 515 pounds of beef produced in 1955 when commercial nitrogen was used at varying rates (Table 6). Thus, when averaged over all nitrogen treatments and grasses, there appeared to be little advantage in substituting commercial nitrogen for clover in 1955.

If the poor response of Coastal Bermuda was deducted from the data in Table 6, there appears to be a greater response to nitrogen fertilizer at the higher levels, than the average response from nitrogen furnished by clovers.

GENERAL DISCUSSION AND CONCLUSIONS

The superiority of Pensacola Bahia to Coastal Bermuda and Argentine Bahia at high levels of nitrogen has not always been reported in the literature(3) for this general area, but it was consistent in these studies. In 1954, when moisture levels were low for the greater part of the growing season, this grass was outstanding in performance at all commercial nitrogen levels. In contrast, when moisture was very favorable in 1955, the increase in yield over the other grasses was barely significant at the five per cent level. This would tend to establish that this grass will respond to high nitrogen as effectively as other major grasses, and in

period of drought, its capacity to use nitrogen may be greater than many other grasses which are available.

The excellent response to nitrogen by Pensacola Bahia in this geographical area may be partially explained on its ability to start growth earlier in the spring than most of the important summer grasses. At the first cutting in 1955, at the 400-pound level, Pensacola Bahia, Coastal Bermuda, and Argentine Bahia produced 3070, 2260, and 2000 pounds of dry forage per acre, respectively. In mid-summer, however, the production was 4600, 5110, and 6075 pounds, respectively (data not shown). The production figures were reversed. Thus, the predomination of Pensacola Bahia must rest solely on its longer period of productivity—that is, by the fact it starts growth earlier in the spring—or on a much greater capacity to produce in the early part of the growing season.

Due to certain fixed costs, the most efficient nitrogen level is not always the most practical level for production. The average response of the grasses to various levels of nitrogen, based on the amount of dry forage produced per pound of nitrogen, was highest at the lowest level of nitrogen applied. As the treatment levels increased, the efficiency of the nitrogen decreased rapidly until the maximum level was reached. From the breakdown in Table 4, it is evident that the column, pounds of forage produced per pound of "N", is not definite enough in the information it contains to determine a practical level of nitrogen for production. The relative efficiency of the nitrogen expended in each increment is probably a much closer estimate of the point of maximum returns from nitrogen than any other in the fertilization program. This point was found to be at the 68-pound increment in 1954, and the 100-pound increment in 1955. The most practical nitrogen rate can be calculated as the 125- and 200-pound treatment levels for each year, respectively. The more favorable moisture level in 1955 probably accounts for the more efficient response to nitrogen than the previous year.

The point of diminishing returns was not found in the nitrogen rates used in 1954, since the increase in yield due to each nitrogen increment resulted in practically a straight line on the response curve. However, in 1955, a definite reversing of curve was noted slightly above the 200-pound increment. It is obvious from the data that, under the conditions which prevailed in these experiments, rates of elemental nitrogen above the 400-pound level would be highly impractical. This is further substantiated from the net worth of dry forage produced per pound of nitrogen expended in the 400-pound increment. The figure of 19 cents worth of dry forage produced for 10.8 cents of nitrogen used is too low a return to be practical.

One of the most important questions arising from the results of these studies arose from the pasture studies. Can we justify the use of commercial nitrogen, as the only source of nitrogen, on land which is capable of supporting "nitrogen-furnishing" clovers?

Information from nitrogen studies in 1955 indicate the beef gains produced in pastures using elemental nitrogen at several rates were not of sufficient magnitude to justify the replacement of clover with commercial nitrogen.

From a three-year study of grazing Pensacola Bahia, Coastal Bermuda, and Argentine Bahia in mixture with several clovers, an average produc-

tion of 463 pounds of beef gain per acre per year was obtained. For equivalent gain from similar pastures, but using commercial nitrogen rates of 100, 200, and 400 pounds of nitrogen per acre instead of clover, it would have required 513, 613, and 813 pounds of beef, respectively, to justify the cost of nitrogen and additional fertilizer applied over that the clover-grass pastures received. These gains were not obtained in 1955. If fixed costs are ignored, and assuming some variability in the experiment, the results indicate that in 1955 clover was equivalent to approximately the 100-pound level of nitrogen.

On land which will not support clover commercial nitrogen is the only source of nitrogen for the growing grass and for the grazing animal. This is an entirely different situation. Under the conditions of this experiment, 374, 324, and 163 pounds of net beef gain were produced above the fertilizer costs, in pounds of beef valued at 16 cents a pound. It is obvious that the most efficient use of nitrogen was at the 100-pound level. Similar experiments at the Georgia Experiment Station by Burton(2) have shown that, up to the 200-pound nitrogen level, they obtained a return of approximately 2 pounds of beef per pound of nitrogen applied above a basic level of 250 pounds of beef gain. This efficiency was not attained in this experiment as the beef gain obtained for each pound of nitrogen applied was only one-half pound at the 100-pound increment, and approximately one-quarter pound for the 200-pound increment.

The grazing studies reported herein were only one year in duration. More years' results are needed to confirm these data and much of that which has been reported in the literature.

SUMMARY

The response to high levels of nitrogen by Pensacola Bahia, Coastal Bermuda, and Argentine Bahia was studied in small plots and in pasture, on the heavier textured soils of Northwest Florida during the period 1952 to 1955.

Pensacola Bahia was consistently superior to both Coastal Bermuda and Argentine Bahia in response to high nitrogen levels in the small plots in 1954 and 1955, and to high nitrogen levels in pastures in 1955.

There was a positive response to nitrogen rates in small plots by all grasses up to the 500-pound level in 1954 and 800-pound level in 1955. The efficiency of nitrogen, as measured in pounds of dry forage produced per acre per pound of nitrogen applied, was highest at the lowest levels of nitrogen applied, and decreased rapidly as the rate of nitrogen increased. The response by the grasses to each increment of nitrogen was a straight line positive curve in 1954, but the response curve leveled off about the 200-pound increment in 1955 and reversed at the 400 increment. The most efficient use of nitrogen was found at the 125-pound level in 1954 and the 200-pound level in 1955.

On the basis of fertilizer costs alone, the information provided from the pasture studies indicated that the response of Pensacola Bahia, Coastal Bermuda and Argentine Bahia to commercial nitrogen rates of 100-, 200-, and 400-pound levels was not of sufficient magnitude to justify replacing clover as a source of nitrogen in pastures.

In both plot studies and pasture experiments, clover as a source of nitrogen was equivalent to approximately 100 pounds of elemental nitrogen in the production of hay or beef.

ACKNOWLEDGMENTS

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PLANT MANAGEMENT INFLUENCES FORAGE YIELD

C S. Hoveland and D. E. McCloud*

Pearlmillet is widely used in the Southeast as a summer annual pasture plant, particularly for dairy cattle. However, little information is available concerning the response of this forage plant to various management practices. For best grazing management it is necessary to know how defoliation of the plant affects the total production, seasonal distribution, and quality of forage. During 1955 an experiment was conducted near Gainesville, Florida, to determine the effect of various defoliation treatments on the forage production of pearlmillet.

PROCEDURE

The experiment was established on Arredondo loamy fine sand using a randomized block design. Two replications received only rainfall and three replications received two supplemental irrigations of two inches each. The entire experiment was irrigated prior to planting to facilitate rapid establishment and a uniform stand. On the irrigated plots, 800 pounds of 3-12-12 fertilizer was applied at planting with four supplemental applications of ammonium nitrate totalling 570 pounds per acre. The unirrigated plots received 800 pounds of 3-12-12 fertilizer at planting and four supplemental applications of ammonium nitrate totalling 465 pounds per acre. Rapid plant tissue tests were used to determine when supplemental nitrogen should be applied. A high level of nitrogen was maintained in the plant tissues. Pearlmillet was planted in thirty-eight inch rows on April 27.

Thirteen cutting treatments were used to simulate different management practices with respect to frequency and severity of defoliation. The plants, on different plots, were cut when they reached heights of 12, 18, 30 and 54 inches. These treatments produced different frequencies of cutting based not on a fixed time interval, but on the rapidity of plant development. Four heights of cut (height of the stubble) were used: 4, 6, 10, and 18 inches. These four heights of cut combined in all likely combinations with the four heights at cutting composed a series of thirteen defoliation treatments. For the sake of brevity in this paper, the cutting treatments will be referred to by numbers, *e.g.* 54-4 means that the plant was cut four inches from the ground each time it reached the 54 inch height.

The cutting was done by means of hand sickles, using as a guide an aluminum pole, the ends of which rested on stakes of the desire height. A 14-foot strip, 1/1000 acre in size was removed for yield. Adjacent rows on either side were cut similarly and served as borders on the three-row plot. The samples were dried at 130°F., weighted and yields recorded as pounds of dry matter per acre.

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* Interim Assistant and Associate Agronomist, Florida Agricultural Experiment Station.

Forage samples were collected from two replications at monthly intervals during the clipping season for nitrogen analysis by the standard Kjeldahl method.

RESULTS AND DISCUSSION

Irrigation gave no significant increase in yield of forage. The irrigation at planting coupled with the two and one-half inches of rainfall during May prevented a severe water shortage and minimized the drouth effect. Since differences between irrigated and unirrigated plots were not significant, all five replications were combined in the statistical analysis.

Highest yields of forage were obtained with the 54-inch growth, cut near the ground leaving a minimum stubble. Yields of dry forage in the test ranged, as shown in Table 1, from 13,070 down to 5,300 pounds of dry matter per acre.

TABLE 1.—Effect of Defoliation on Forage Production of Pearlmillet.

Height of Foliage at Cutting Inches	Height of Cut (Stubble Height) Inches	Yield of Oven Dry Forage Pounds per Acre
54	4	13,070
54	6	12,200
54	10	11.080
54	18	7,950
30	4	8,940
30	6	9,350
30	10	8,260
30	18	8,800
18	4	6,080
18	6	6,350
18	10	7,210
12	4	5.300
12	6	5.310
	LSD 5%	1,350
	1%	1,800

Forage production of pearlmillet increased progressively as the plants were permitted to grow taller before clipping. Plants cut when 54 inches tall produced over two and one-half times as much forage as plants that were cut when they reached 12 inches tall.

Plants 54 inches tall showed a progressive decline in forage yield as the cutting height was increased. Cutting of 54 inch plants at 18 inches decreased the yield of forage by one-third as compared to that of the 54-4 cut. This yield reduction can be explained by the large amount of forage left in the higher stubble.

It will be noted that there was no significant difference in total yield between the 30-4, 30-6, 30-10, and 30-18 cutting treatments. In spite of considerable forage not harvested in the high stubble of the 30-18 treatments, the season total yield was the same as the low stubble plants. Millet plants harvested when 30 inches tall and cut to leave higher stubble tillered out at the top of the cut stems, making their regrowth from this

point rather than from the base of the plant. Although this phenomena occurred with plants harvested when 54 inches tall, it was not as pronounced and regrowth was slower. Yields decreased more sharply in late summer on plants having an 18-inch stubble.

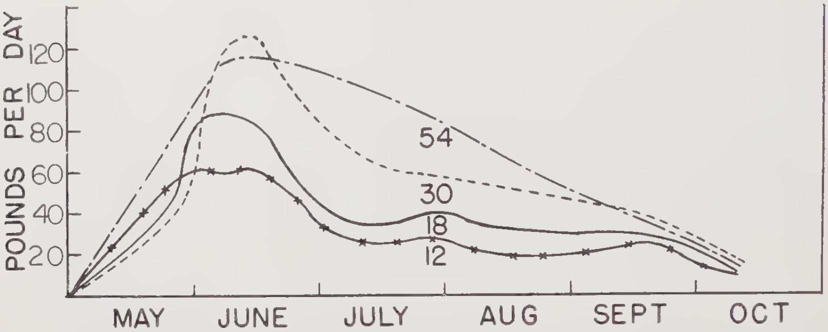

Figure 1.—Daily production of pearlmillet in pounds dry matter per acre for various heights at cutting. Gainesville, Florida, 1955.

Daily production of pearlmillet clipped at four heights was calculated from the harvest data and is presented in Figure 1. Since height of stubble had very little influence on forage yield, the various heights of cut were averaged together in the graph. Peak production for all treatments was reached in early June after which there was a gradual decline. Plants cut when they reached heights of either 54 or 30 inches continued to produce more forage in late summer than did plants harvested when either 12 or 18 inches tall. For the 30-inch plants, yields ranged from 110 to 40 pounds of forage per day.

As might be expected, the clipping treatment had considerable influence on forage quality. This was noted by visual observations and measured by crude protein determinations. As expected, the crude protein content of the forage was influenced primarily by the height of the plants when they were cut (Table 2). As plants were permitted to grow taller before cutting, the protein content decreased. Plants clipped frequently (12 or 18 inches tall) maintained a higher protein content throughout the season than plants clipped less often. There was a small decline in protein content toward the end of the growing season, the decrease being more pronounced in the less frequently clipped plants, those cut when 54 or 30 inches tall.

It was expected that protein contents would be influenced by the height of the stubble. However, this generally did not occur. Protein contents were largely dependent upon the height of the plant prior to cutting and showed a surprising uniformity when only the height of the stubble was varied. The only exception was the 30-inch plants cut with an 18-inch stubble which did have a slightly higher protein content. The change in growth pattern with a branching and regrowth from the top of the stubble accounted for this higher protein content.

From this study it would appear that in pearlmillet pasture management, the severity of defoliation or height of stubble left has a minor

effect on forage yields and protein content. Close cutting or grazing in itself does not materially reduce forage yield or protein content. The chief factor affecting yield and protein content is the height of the plants when grazing is begun.

TABLE 2.—EFFECT OF DEFOLIATION ON CRUDE PROTEIN CONTENT OF PEARLMILLET.

Height of Forage at Cutting	Height of Cut (Stubble Height)	Crude Protein		
		June	July	August
Inches	Inches	Percent	Percent	Percent
54	4	18.1	16.2	14.4
54	6	19.4	19.4	11.7
54	10	19.2	17.0	12.8
54	18	—	17.2	14.1
30	4	21.6	22.5	14.4
30	6	22.4	20.4	14.3
30	10	22.7	20.4	13.0
30	18	23.1	23.3	18.8
18	4	24.9	26.0	23.8
18	6	27.1	25.7	23.5
18	10	24.8	25.2	20.4
12	4	28.1	25.8	23.8
12	6	27.2	30.4	25.7

SUMMARY

A pearlmillet management study, using thirteen cutting treatments, was conducted near Gainesville, Florida, in 1955. Height of the plants when cut and heights of the stubble left were studied.

Forage production increased as the plants were permitted to grow taller before clipping. Production continued to be high over a longer period of time with the taller growing plants. Frequent defoliation decreased the yield throughout the season.

Height of the stubble had no influence on the yield of plants clipped when 12, 18, or 30 inches tall. Plants 54 inches tall progressively declined in forage yield as the cutting height was increased.

Protein contents in general decreased as plants were permitted to grow taller before clipping. Height of the stubble had little influence on protein content.

ACKNOWLEDGMENTS

Nitrogen determinations were made in the Agronomy Department Analytical Laboratory under the supervision of Dr. Henry C. Harris.

PASTURE MANAGEMENT IN CENTRAL FLORIDA

E. M. Hodges*

"Good pasture management is the art and science of handling the pasture so as to obtain maximum production and at the same time conserve the stand of grass." So wrote H. W. Staten, in his excellent book on Grasses and Grassland Farming (Devin-Adair Company, New York. 1952).

This definition may well be applied to the Central Florida peninsula. Maximum production, from the standpoint of efficiency, is certainly a prime need in the present economic situation of the cattle industry. One step toward this objective is increased per-acre production. Almost all pasture improvement practices have some influence on yields. The early stage of improvement, consisting of wiregrass and palmetto destruction and planting of carpet and common bahiagrasses, gave increased production. Plant food application together with rotational and deferred grazing have increased the yields of forage and helped provide more feed for a cattle population that had long been subject to periods of starvation.

Increased nutritional value of forage has been a second result of the pasture development and management program. The wiregrass provides excellent protein values during the early weeks of growth but matures rapidly, with protein content dropping to levels which will not give satisfactory maintenance and growth of livestock. Our sandy soils do not supply adequate mineral nutrition for either native or planted forage varieties. The fertilization practices employed to increase yields have vastly influenced feed value as well. It has been observed that while mineral nutrition is improved for several months up to several years following treatment, nitrogen applications produce rapid protein quality response which is largely lost in four to eight weeks. Repeated application of nitrogenous fertilizers is required if an area of grass pasture is to be kept in a growing and nutritious condition.

The rapid decline in feeding value of native pasture, following the spring flush of growth, is closely linked with the whole problem of large seasonal variation in amount and value of feed available on native ranges. Chief among the reasons for developing improved pasture has been the need for more and better feed during the period December to April. Even in the face of the great need for winter feed, there has been a tendency for improved pasture projects to emphasize spring and summer production, a result of the plentiful moisture supply during this period of the year.

There is a growing realization of the value of the seasonal feed control that can be obtained by proper timing of fertilizer applications. The time of forage availability in itself may be even more valuable to the livestock producer than are increases in yield and nutritional quality of forage. Dry winters are characteristic of this area of the state. Grass that is produced in late summer and fall can be left in the field for midwinter

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* Agronomist, Range Cattle Station, Ona, Florida.

grazing. Pangolagrass is best-suited for this use, but other improved varieties and even native range can be used in the same way. This deferred grazing practice undoubtedly has its greatest value in the Central Florida area and should be seriously considered in all pasture management plans.

Pasture production and grazing cannot be discussed without some reference to the place of legumes in the pattern. The small acreage that these plants occupy in our present forage situation is indicative of our need for new varieties and more information about the use of the ones now available.

The value of legumes in taking nitrogen from the air is classic and strongly influences the economy of production. The growth habits that make legumes available at seasons of the year when grasses are in a decline place a premium on them in our pastures. White clover has high grazing value during spring and summer but the feed obtained from January to March is most important. Methodical control of grazing, fertilization and water conditions are absolute essentials to the use of this legume. Alyceclover and hairy indigo, as warm-season species, have excellent nutritional value and lengthen the period of high-quality grazing without the use of intensive fertilization methods.

Returning to our original definition, conservation of grass stand is more important than might be apparent. Pangola, our most productive grass variety can be and is being damaged by continued overstocking. Lowered production and invasion of the sod by less productive plants is the result of lack of careful management. Pensacola bahia, while somewhat less productive than pangola, is not subject to permanent damage by overstocking. A balance of these species with dierent characteristics is of value to a successful pasture and grazing system.

The use of stored and purchased feed in relation to pasture management has not been discussed here. This is actually a most important consideration, presenting separate and yet related practices that must be blended into the livestock production program.

The details of pasture production and use are many and changing and their detailed enumeration would not further emphasize the value of careful attention to the factors of pasture production and use. We can be confident that more forage of higher quality, that is available when needed is the result of good pasture management. This must be matched with efficient animal management to insure the future well-being of our cattle industry.

TOTAL AND INORGANIC SULFUR CONTENTS OF VARIOUS EVERGLADES FORAGES

Albert E. Kretschmer, Jr.*

The effect of copper and molybdenum on the nutrition of ruminants have been studied for many years. Certain apparent nutritional disorders found in cattle grazing pastures on the organic soils of the state, led to studies dealing with these elements(1, 3, 4, 5). Kretschmer and Beardsley(7), recently reviewed the work that has been done at the Everglades Experiment Station in an attempt to solve an apparent nutritional problem in cattle associated with copper and molybdenum.

Dick was the first worker to find that the inorganic sulfate intake had a marked effect on the molybdenum and copper nutrition of sheep. In a recent paper(2) he discussed thoroughly the effects of copper, molybdenum and sulfate-sulfur intake on the nutrition of sheep. He explained the results of experimental work on the hypothesis that inorganic sulfate interferes with the transport of molybdenum across animal membranes and that such a membrane, at which molybdenum is blocked, impedes the transport of copper. If the sulfate intake is sufficiently high there will be little or no movement of molybdenum across the membrane, and if the concentration of the "blocked" molybdenum is high enough little or no copper will be transported.

Because of the inconsistencies in experimental results obtained in nutritional studies at the Everglades station with cattle, and because of the pronounced effects of sulfate-sulfur on the copper and molybdenum nutrition of sheep, analyses were made of soils and forages of the Everglades area to determine the quantities of total- and sulfate-sulfur present.

METHODS

Samples were obtained and prepared in a manner explained in previous work(5, 6).

Total sulfur determinations were made gravimetrically, by precipitating the sulfur in nitric-perchloric acid plant or soil digests with barium chloride.

Inorganic sulfate, in this paper, was considered to be that portion of the sulfur extracted by a 10 per cent solution of trichloroacetic acid. In most instances, 2 grams of finely ground, oven-dry plant material were extracted with 50 ml. of the acid, and the sulfur was precipitated as barium sulfate from a 25 ml. aliquot of the extract.

It was found[1] that this method was accurate in the determination of added inorganic sulfate to plant material, and our results indicated that the method at least accounts for the easily extractable sulfur, the greater portion of which would be in the form of sulfate.

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* Assistant Soils Chemist, Indian River Field Laboratory, Ft. Pierce, Florida.

[1] Personal communication from Dr. G. P. Lofgreen, Department of Animal Husbandry, California Agricultural Experiment Station; Davis, California.

PROCEDURES AND RESULTS

Soils

Analyses of nine samples collected from various organic soil types indicated that the total sulfur contents varied from 0.37 to 0.86 per cent. One sample of virgin Loxahatchee peat contained 0.70 per cent sulfur, while an area that had been farmed for many years, and had received large applications of calcium sulfate in the form of superphosphate, contained 0.86 per cent. Old vegetable soils would generally be expected to contain more sulfur because of the additions of this element from superphosphate and from sulfur applications (which are used in many instances to reduce the soil pH).

Effects of Soil Amendments

In an effort to determine the effects of lime and sulfur additions to "old" Everglades peaty muck soil. 3 tons of hydrated lime and 1000 pounds of sulfur per acre each were disked into the soil of four replicated plots, in the fall of 1954. Alfalfa and Louisiana white clover, seeded in the fall, were sampled June 1, 1955, in all of the treated and the check plots. They had been mowed twice previously. Average 0 to 1, 1 to 3, 3 to 6, and 0 to 6 inch soil samples taken in April from the check, sulfur,

TABLE 1.—The Effect of Soil Treatment on the Sulfur Contents of Alfalfa and Louisiana White Clover.

Treatment	Total Sulfur %		Sulfate-Sulfur* %		Ratio S.S./T.S.** %	
1. Check	0.25		0.07		27	
2. Sulfur—1,000 lbs. per acre	0.26		0.09		31	
3. Hydrated lime—3 tons per acre	0.27		0.10		34	
L.S.D.—.05	N.S.		0.02		5	
Variety						
1. Alfalfa	0.32		0.14		44	
2. White Clover	0.20		0.04		18	
L.S.D.—.01	0.03		0.02		19	
Interaction	Alf.	Wh.Cl.	Alf.	Wh.Cl.	Alf.	Wh.Cl.
1. Check	0.30	0.20	0.12	0.03	39	15
2. Sulfur—1000 lbs. per acre	0 31	0.22	0.14	0.04	45	18
3. Hydrated lime—3 tons per acre	0.35	0.19	0.17	0.04	47	21
L.S.D.—.05	0.04		0.02		N.S.	

* Values are reported as Sulfur.
** Calculated by dividing sulfate-sulfur by total-sulfur x 100.

and lime plots, had pH values of 6.02, 5.90, 5.83, 5.87; 4.97, 5.66, 5.81, 5.52; 7.57, 6.33, 5.90, 6.45, respectively.

As shown in Table 1, there was a large difference in the sulfur contents between species. The effects of treatment were slight. Not only did the clover contain less total- and sulfate-sulfur but the per cent sulfate-sulfur was less than half that of the alfalfa. An interesting point to emphasize is that 1000 pounds of sulfur per acre disked in had little effect on the total- or sulfate-sulfur contents of either variety.

Effects of Season

Three grazing trial pastures at the Everglades Station were chosen for a test to observe the effects of season on the variation in sulfur contents of Roselawn St. Augustinegrass, caribgrass and paragrass. Eight samples of each species were taken periodically for a period of approximately one year. There was no difference in total-sulfur, sulfate-sulfur, or per cent sulfate-sulfur contents as a result of different sampling dates. The values ranged from 0.32-0.39, 0.09-0.18, and 26-46 per cent, respectively. Species differences are reported in Table 2. Not only did the paragrass contain smaller quantities of total-sulfur but the sulfate-sulfur contents were only about one-half that for the other species. Although part of this difference may have been the result of differential fertilization through the years, the important point is that differences in sulfate-sulfur contents of different grass species do exist.

TABLE 2.—The Sulfur Contents of Three Permanent Pasture Grasses.

Grass*	Total-Sulfur %	Sulfate-Sulfur** %	Ratio S.S./T.S.† %
1. Caribgrass	0 40	0.15	37
2. Roselawn St. Augustinegrass	0.37	0.19	50
3. Paragrass	0.32	0.08	25
L.S.D.—.05	0.04	0.05	12
L.S.D.—.01	0.05	0 07	16

* Caribgrass and paragrass samples included all plant fractions above uppermost mature node while the St. Augustinegrass samples included leaf blades only.

** Values are reported as Sulfur.

† Calculated by dividing sulfate-sulfur by total-sulfur x 100.

Effects of Species

Ten forages were grown in quadruplicate in Everglades peaty muck soil in 4-gallon pots in the greenhouse. Fertilization of all pots was adequate and equal. Samples from the third cutting were analyzed for sulfur. Results are shown in Table 3. Differences in the total- as well as in the sulfate-sulfur contents are rather large. It should be pointed out that there does not appear to be any correlation between either the total- or sulfate-sulfur contents and the per cent sulfate-sulfur.

TABLE 3.—THE SULFUR CONTENTS OF TEN FORAGES GROWN IN EVERGLADES PEATY MUCK SOIL IN THE GREENHOUSE.

Forage	Total-Sulfur %	Sulfate-Sulfur* %	Ratio S.S./T.S.** %
1. Roselawn St. Augustinegrass	0.59	0.53	90
2. Tall Fescue, 19G1-25	0.55	0.39	70
3. Bermudagrass	0.55	0.39	73
4. Louisiana white clover	0.48	0.36	75
5. Tall Fescue, Kentucky 31	0.46	0.30	64
6. Pangolagrass	0.46	0.35	76
7. Caribgrass	0.41	0.31	75
8. Pensacola bahiagrass	0.38	0.28	73
9. "Giant" pangolagrass	0.31	0.24	78
10. Paragrass	0.27	0.18	67
L.S.D.—.05	0.12	0.11	10
L.S.D.—.01	0.16	0.15	14
1. Caribgrass stems	0.44	0.40	91
2. Pangolagrass stems	0.34	0.25	74
3. St. Augustinegrass	0.30	0.23	77
4. Paragrass stems	0.26	0.15	56
L.S.D.—.05	0.06	0.08	N.S.
L.S.D.—.01	0.09	0.11	

* Values are reported as Sulfur.

** Calculated by dividing sulfate-sulfur by total-sulfur x 100.

SURVEY

To obtain some indication as to the amounts of sulfur absorbed by Roselawn St. Augustinegrass, 21 samples of the grass obtained from various pastures in the area were analyzed for sulfur. Total-sulfur contents ranged from 0.27 to 0.68 per cent; sulfate-sulfur contents ranged from 0.08 to 0.53 per cent; and per cent sulfate-sulfur ranged from 23 to 84. Averages were 0.40, 0.24, and 60 per cent, respectively. Results of the survey indicated that a large variation existed in the total- and sulfate-sulfur contents of Roselawn St. Augustinegrass. It is believed that similar variations would exist for other permanent grasses.

DISCUSSION

Dick indicated(2) that he was unable to demonstrate any effects of molybdenum on the copper metabolism of sheep which were not dependent on the sulfate intake. At very low levels of sulfate intake, there were no effects on the blood copper concentration at any level of molybdenum intake from 0.3 to 100 mg. per day. When the sulfate intake was increased through a range of 0.5 to 5.0 gm. per day there was an immediate rise in blood copper, and loss in tissue copper; the greatest rise being found at the highest molybdenum and sulfate levels. This effect was found to take place over a longer period of time at lower sulfate and molybdenum levels. These elevated blood copper values fall sharply to the levels encountered in copper deficiency as soon as the tissue, mainly liver, is depleted of copper. The effects of sulfate and molybdenum on

liver copper storage indicated further the importance of sulfate in the nutrition of sheep. With a daily intake of 9.1 mg. copper, Dick found that 14.7 mg. molybdenum per day completely blocked the accumulation of copper in the liver, when the sulfate intake was 1.4 gm. per day. The same blocking effect was brought about by a molybdenum intake of only 5.3 mg. per day when the sulfate intake was increased to 2.5 gm. per day.

In an examination of the total- and sulfate-sulfur contents of the forages grown on the organic soils of the Everglades, and how they might or might not effect the nutrition of cattle, one further point should be mentioned. When the protein content of the forage is in excess of the needs of the animal, a certain portion of the organically-bound sulfur will be converted in the rumen to sulfate-sulfur and will act as such. This would be the case a majority of the time under Everglades conditions where protein contents of forages generally exceed the protein requirements of cattle.

It has been demonstrated(7) that the copper and molybdenum contents of forages are affected by species and season. Although the effect of season does not seem to play an important role in the total- or sulfate-sulfur contents of permanent pasture grasses, there are large differences found between grass as well as legume species. Also, large differences were found in the sulfur contents of Roselawn St. Augustinegrass samples taken from various locations in the Everglades. Cattle consuming ten pounds of dry Roselawn St. Augustinegrass would have an intake of 3.6 gm. of sulfur, 12 gm. sulfate, based on an 0.08 per cent sulfate-sulfur content and 24 gm. sulfur, 80 gm. sulfate, based on a 0.53 per cent sulfate-sulfur content. These represent the extreme sulfur contents found in St. Augustinegrass from the survey work. It appears that most of the forages considered in this paper, except the white clover samples from the soil amendment test, would be on the medium to high side with respect to the quantity of sulfate-sulfur consumed by cattle grazing them. The high sulfate-sulfur contents of some of the samples analyzed might explain, according to Dick's thesis, how the low levels of molybdenum 2-3 ppm., found in forages growing in this area could affect the copper status of cattle grazing these forages.

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BANQUET AND BUSINESS MEETING

The regular business meeting of the Society followed immediately after the annual banquet which was held in the main dining room of the Orange Court Hotel on the evening of November 30 when Provost W. M. Fifield acted as Master of Ceremonies. Drs. L. A. Richards of U. S. Salinity Laboratory, Riverside, California and R. L. Mitchell, Macaulay Institute of Soil Research, Aberdeen, Scotland, were entertained as special guests at that time.

The principal business to come before the business meeting, which was presided over by President F. H. Hull, pertained to the change of name for the Society that was discussed at some length last year. In accordance with instructions received at that time the membership was canvassed during the year by ballot sent out as first class mail regarding such change of name *from* The Soil Science Society of Florida *to* The Soil and Crop Science Society of Florida. The returns from this balloting to the dates indicated, November 20 being the first deadline set, was found to be as follows:

	For Change	*Against Change*	*Total*
To November 20	291	149	440
Additional to November 29	11	6	17
Total	302	155	457

The total number of ballots sent out was 948, none having been sent to foreign members for obvious reasons. Thus somewhat less than half were returned and of this number the vote was only a little less than 2 to 1 in favor of the name change. As soon as the results were made known there was a motion of acceptance from the floor which was promptly seconded and passed by voice vote, unanimously.

President Hull then asked for the report of the Secretary-Treasurer on membership, finances and publications and for the report of the Resolutions Committee.

MEMBERSHIP

The present state of the membership of the Society can best be shown by comparing the various categories thereof with their status last year. This gives us the figures shown on next page which, of course, do not include those copies of the Proceedings sent to libraries either on a free or subscription basis.

From these figures it is seen that quite a substantial growth has been experienced during the year. In the "Sustaining" category this has been due in good part to the excellent response that followed a letter of invitation to membership addressed to all fertilizer manufacturers and distributors having interest in Florida problems in this field.

I am glad indeed to report that the Soil Science Society of Latin America is thriving well under the guidance of Sr. Ing. Antonio Arena whose address is Centro Panamericano de Recursos Naturales, Avda. Churchill, 129,

estritorio 1204, Rio de Janeiro, Brazil, S. A. As some of you know, Mr. Arena, originally from Buenos Aires, is an excellent Soil Scientist and a very hard worker.

	Annual		Sustaining		Honorary Life		Total	
	1954	1955	1954	1955	1954	1955	1954*	1955*
Florida	571	661	78	104	1		649	765
U. S. (other than Florida)	196	181	37	45	8	8	233	234
Craibbean area	122	128	5	5			127	133
Foreign (other than Caribbean)	30	36	6	7	2	2	36	45
Total	919	1006	126	161	11	10	1056	1177

* As of December 31, in each instance.

As some of you also know, we have been in correspondence for a number of years with Mr. Arena, Dr. Popenoe and others of our Latin American members in the interest of developing a Symposium on Tropical Soils at one of our future meetings. If this is done it is hoped, of course, that it will be under the capable leadership of Dr. Gaylord Volk, Chairman of our Tropical Soils Committee who has himself had considerable experience with tropical soils.

REPORT OF THE TREASURER

Statement of Receipts and Disbursements Year Ending

December 31, 1955*

Cash in Bank 12/31/54		
Everglades Federal Savings & Loan Co.	$3,622.34	
Florida National Bank	2,442.11	
		$6,064.45
Receipts—Dues collected, Proceedings sold and interest		4,658.00
Total monies to be accounted for		$10,722.45
Disbursements		
Office supplies	$ 61.13	
Postage	292.41	
Printing—Publications	2,019.23	
Payroll	825.00	
Bank charges	.25	
Expenses—annual meeting (1954)	19.83	
Expenses—annual meeting (1955)	500.96	
Travel	49.12	
		3,767.93

* Approved by the Auditing Committee, Dr. Victor E. Green, Chairman.

Cash in Bank 12/31/55	
Everglades Federal Savings & Loan Co.	$3,750.24
Florida National Bank	3,204.28
	6,954.52
Total monies accounted for	$10,722.45

PUBLICATION

Again the Editor has little to report except to gratefully call attention to the excellent help with getting Proceedings Volume XIV to press which was furnished by Dr. Wander and his Committee consisting of the Chairmen of the various symposia.

A total of 1,140 copies of Proceedings Volume XIV was published of which 1,145 were mailed from Gainesville on Friday, Nov. 25, only 3 days before the opening of the present meeting.

Largely in consequence of added equipment, the press service at Pepper Printing Company has improved markedly during recent months to the point that I am confident if we will get copy to them of Proceedings Volume XV by early January we can have it ready for mailing in two to three months. By improvement as to service reference is entirely to the matter of time. The quality of the work of this shop has been all but impeccable for many years as those of you well know who have been in personal contact with it.

The speeding up of the printing service is proving of significant assistance too, in getting our backlog of printing caught up. Progress with this is now improving rapidly. However, it must always be remembered that it is impossible to get the current Proceedings to and thru the press promptly except with the full cooperation of those whose papers are to be published.

REPORT OF THE RESOLUTIONS COMMITTEE

A Resolution of Sympathy was read by the Secretary which told of the Society's loss by death during the year of nine members. The reading was followed by a brief period of silence at the request of the President. The Resolution is published in full in this Volume on page 256.

REPORT OF NOMINATING COMMITTEE AND ELECTION OF NEW OFFICERS

The Nominating Committee appointed by President Hull about a week in advance of the Annual Meeting consisted of J. R. Henderson, E. L. Spencer and Nathan Gammon as Chairman. Shortly after the opening of the meetings the group was charged with the added duty of bringing in a nomination for President as well as Vice President. This was due to the fact that Vice President Walter Reuther, who automatically was to become President of the Society, had only recently resigned as Head of the Department of Horticulture in the University at Gainesville, effective February, 1956, to accept a position in the California Experiment Station at Riverside.

In succession the committee recommended Dr. R. W. Ruprecht, Vice Director in Charge, Central Florida Experiment Station, Sanford for President and Dr. D. E. McCloud, Department of Agronomy, Agricultural Experiment Station, Gainesville, for Vice President. There being no nominations from the floor in either instance, each, in turn, was elected by acclamation and the Secretary instructed by the President to cast a unanimous ballot in that behalf.

Following the election of the new President Dr. Hull promptly turned the meeting over to Dr. Ruprecht and automatically took the place of former President E. L. Spencer as a member of the Executive Committee.

President Ruprecht's first act was to ask that each symposium leader serve as a member of the Publications Committee and plan to get all of his manuscripts in to the Editor just as soon as possible. This group consists of Walter Reuther, Gaylord M. Volk, John W. Sites and D. E. McCloud. He also called attention to the fact that Vice President McCloud would be primarily responsible for the development of the program for the Annual Meetings of the coming year.

There being no other business to come before the meeting it was adjourned at 10:30 P.M. after a call by the President for a brief meeting of the Executive Committee immediately following the close of the business meeting.

MEETING OF EXECUTIVE COMMITTEE

The meeting of the Executive Committee was called to order by President Ruprecht who presided as Chairman.

The position of Secretary-Treasurer having become automatically vacant at the close of the year, R. V. Allison was requested again to serve in this capacity for the calendar year 1956.

The place of the next meeting was discussed at length and from among several invitations received, Clearwater was tentatively decided on with Hotel Fort Harrison as headquarters. Confirmation of this selection as well as definite dates some time late in November was promised the officials of that hotel in the near future.

At the invitation of President Ruprecht it was decided to hold the next Spring (Interim) meeting at Sanford with favorable thought given to making it a joint affair with the Potato Field Laboratory at Hastings provided a favorable date could be worked out for both places.

Considerable discussion was given to the subjects for development at the next Annual Meeting. Most favorable thought and attention was given to a full day on Florida's water problems; and a symposium of normal length on weed control.

An appropriate expression of sincere thanks was made of record to the officials of the Orange Court Hotel, the Orlando Chamber of Commerce and all who took an active part in the program or otherwise assisted with it for their good help in making this one of the most successful meetings yet held by the Society.

There being no other business to come before the Committee the meeting was declared adjourned by the Chairman at 11:15 P.M.

RESOLUTION OF SYMPATHY

WHEREAS, death has taken from our rolls during the year the following esteemed members of the Society whose sincere and constructive interest in all aspects of the work will make their absence keenly felt for a long time to come,

NOW, THEREFORE, BE IT RESOLVED, that this expression of sorrow over this great loss and of sympathy to the immediate families of the deceased be spread upon the records of this Society and a copy of same be sent to the closest member of the family of each.

1. Emile Babcock
   Daytona Beach
2. Fred F. Coffee
   Jacksonville
3. John Gordon DuPuis, M.D.
   Miami
4. Goro Kawasumi
   Tokyo, Japan
5. C. B. Moak
   Miami
6. Robert M. Salter
   Beltsville, Md.
7. Charles R. Short
   Clermont
8. W. T. Whitney
   Plant City
9. C. T. Young
   Plant City

FRED H. HULL

WALTER REUTHER

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1955—Retired

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Walter Reuther	Vice President
Ernest L. Spencer	Past President
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Allee, Dr. Ralph H., P. O. Box 74, Turrialba, Costa Rica, C. A.
Allen, Edward J., 2150 N.W. 17th Ave., Miami 42
Allen, Dr. Robert J., Jr., Everglades Experiment Station, Belle Glade
Allen, Sherman, % Walter Drey, Inc., 257 Fourth Ave., New York 10, N. Y.
Allison, Eaves, Box 365, Sarasota
Allison, Dr. Ira, M.D., 1515 Washington Ave., Springfield, Missouri
Allison, Dr. Robert V., Everglades Experiment Station, Belle Glade
Alphin, B. W., P. O. Box 599, Jacksonville
Amador, Julio, Instituto Mexicano de Inves. Tec., Legaria 694, Mexico 10, D. F.
American Liquid Fertilizer Company, Marietta, Ohio
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Anderson, Mrs. Harold, 666 49th St., S., St. Petersburg
Anderson, Dr. Myron S., Plant Industry Station, U.S.D.A., Beltsville, Maryland
App, Dr. Frank, Seabrook Farming Corporation, Bridgeton, New Jersey
Araneta, Vicente A., 343 Echague, Manila, Philippines
Archbold, John D., 39 East 79th St., New York, N. Y.
Arena, Ing. Agron. Antonio, Centro Panamericano de Recursos Naturales, Avda Churchill, 120-esretorio 1204, Rio de Janeiro, Brazil, S. A.
Arey, Philip S., Box 2288, Orlando
Arey, Wallace J., Box 225, Plymouth
Ariet, Mario R., Edificio Payret, Prado y San Jose, Havana, Cuba
Ariza, Rodolfo Riviera, 3a Calle de Tivoli, No. 6-52, Guatemala City, C. A.
Arkell, William C., Room 3101, 10 East 40th Street, New York 16, N. Y.
Armor, J. O., P. O. Box 190, Plant City
Arnold, H. P., The Derwood Mill, Derwood, Maryland
Arny, L. Wayne, R. D. 2, West Chester, Pennsylvania
Arrieta, Alberto, 312 Bamboo Rd., Riviera Beach
Arschwager, Ernst, 540 Brown Road, Las Cruces, N. M.
Aspiazu, Senador Miguel, Apartado 710, Guayaquil, Ecuador, S. A.
Atlas Fish Fertilizer Co., 1 Drumm St., San Francisco, Calif.
Aycock, William C., P. O. Box 38, Lake Park
Ayers, Ed L., State Plant Board, Seagle Building, Gainesville
Baetzman, Fred E., Court House, Orlando
Bailey, Karl D., 5275 Adams Road, Birmingham, Michigan
Bair, Dr. Roy A., 256 Alhambra Place, West Palm Beach
Baird, Guy B., Apartado Aero 58-13 Bogota, Colombia, S. A.
Baker, Aaron S., Box 470, Quincy
Baker, C. M., Reynolds Jamaica Mines, Ltd., Lynford Post Office, St. Ann, Jamaica
Baker, Gerald F., Box 38, Dania
Baker, Dr. John H., President National Association Audubon Societies, 1006 5th Avenue, New York, N. Y.
Baker, M. A., R.F.D. No. 2, P. O. Box 342, Homestead
Baker, O. Sproule, 358 N.W. 27th Ave., Miami 35
Bales, I. W., Chipman Chem. Co., Inc., Bound Brook, N. J.
Ballard, Jack K., 1903 Palmyra Rd., Albany, Georgia
Ballentine, C. C., P. O. Box 3751, Orlando
Bamford, W. C., P. O. Box 366, Belle Glade
Barber, Bascom D., P. O. Box 685, Clearwater
Barcus, David L., 1434 West Main St., Leesburg
Barnard, Edward R., 111 Palmetto Road, Clearwater
Barnes, Robert L., School of Forestry, Univ. of Fla., Gainesville
Barnett, W. L'E., P. O. Box 13, Tangerine
Barrows, Harold L., Box 2817. Gainesville
Barrs, Carrington, 3403 Morrison Ave., Tampa

Bartlett, F. David, 112 No. First Ave., Clayton, N. M.
Bascones, Luis, URB, Washington Ave., Miranda Qta. Rios-Caracas, Venezuela, S. A.
Baskin, J. L., 1230 Golden Lane, Orlando
Batista, J. W., Central Tacajo, Prov. Oriente, Cuba
Beardsley, Daniel W., Everglades Expt. Sta., Belle Glade
Beardsley, J. E., Clewiston
Beardsley, J. W., Clewiston
Beardsley, V. R., Clewiston
Beauchamp, C. E., Manzana de Gomez 516, Havana, Cuba
Beavers, Alan B., 1028 27th St., Orlando
Beckenbach, Dr. J. R., Agricultural Experiment Station, Gainesville
Bedell, Howard, National Spectrographic Laboratories, Inc., 6300 Euclid Avenue, Cleveland 3, Ohio
Beem, Jean, Court House, Tampa 2
Beeson, Dr. Kenneth C., 214 N. Triphammer Road, Ithaca, New York
Belcher, Bascom A., P. O. Box 421, Canal Point
Bell, Donald H., Rt. 2, Box 236, Lake Worth
Bell, Joe O., Box 302, Ft. Myers
Bennett, Dr. H. H., 5411 Kirby Road, Falls Church, Virginia
Benson, David A., Box 2288, Orlando
Berg, Ernest, 345 Little East Neck Road, Babylon, Long Island, New York
Bergeaux, P. J., Tennessee Corporation, East Point, Georgia
Berry, Miss Frances, 821½ Ardmore Rd., West Palm Beach
Bertramson, B. Rodney, State Col. of Washington, Pullman, Wash.
Bestor, Horace A., Clewiston
Bills, Jeanne Bellamy, 2917 Seminole St., Miami 45
Birchfield, Wray, State Plant Board, Lake Alfred
Birdsall, Dr. Benjamin, Box J, Balboa, Canal Zone
Bishop, W. A., Howard Fertilizer Co., Box 3028, Orlando
Bissett, Owen W, 1340 Lake Mirror Dr., Winter Haven
Bistline, F. W., Box 87, Longwood
Bitting, Bruce, 2100 N.W. 120th St., Miami
Blackmon, G. H., Florida Agricultural Experiment Station, Gainesville
Blank, J. Ralph, P. O. Box 107, West Palm Beach
Bledsoe, Roger W., Newell Hall, U. of Fla., Gainesville
Blickersderfer, Clark B., Rt. 3, Box 187-P, Bradenton
Bloom, Dr. Betty Bradford, 1400 Fairmont St., N.W., Washington 9, D. C.
Blue, Dr. William G., Florida Agricultural Experiment Station, Gainesville
Bninski, Konrad, P. O. Box 714, Delray Beach
Bogart, Dean B., Federal Bldg., Albany, New York
Bonazzi, Augusto, Facultad de Ingenieria Agron., Maracay, Venezuela, S. A.
Bonnet, Dr. J. A., P. O. Box 591, Rio Piedras, Puerto Rico
Borchardt, E. H., E. H. Borchardt Co., Boynton Beach
Bornstein, Julian, 638 W. Hazel Ave., Orlando
Boss, Manley L., Botany Dept., Univ. of Miami, Coral Gables 46
Bourland, V. E., Winter Garden
Bourne, Dr. B. A., U. S. Sugar Corporation, Clewiston
Boy, J. B., U. S. Sugar Corporation, Clewiston
Boyd, F. E., P. O. Box 120, Montgomery, Alabama
Boyd, Dr. Frederick, Plantation Field Lab., 5305 S.W. 12th St., Ft. Lauderdale
Boyd, Dr. Mark F., 615 East 6th Avenue, Tallahassee
Boynton, L. Ralph, U. S. Potash Company, 1225 Rhodes Haverty Building, Atlanta, Georgia
Bozard, James D., Atlantic Coastline RR Co., Sanford
Brambila, Miguel, Sria. de Recursos Hidraulicos, Mexico (1) D. F.
Brandes, Dr. E. W., Palm Beach Research Farm, P. O. Box 361, Canal Point
Brass, L. J., Archbold Biological Sta., Lake Placid
Breland, Dr. Herman L., Dept. of Soils, University of Florida, Gainesville
Brewer, D. T., % County Agents Office, Orlando
Brewer, W. W., 7110 Loarsey, Tampa
Brewton, William S., 1115 Anastasia Ave., Coral Gables
Brian, C. E., Drawer 4459, Jacksonville
Bridge, C.J.R., Barton Ramie Estate, Baking Pot P. O., British Honduras
Brill, Philip G., State Plant Board, Lake Alfred
Brockway, E. K., Box 695, Clermont
Brouillette, George P., P. O. Box 803, Clermont
Brown, Cal H., P. O. Box 601, Fort Pierce
Brown, Harry C., Clermont
Brown, Harvey, Rt. 2, Box 274, Hawthorne
Brown, J. W., 485 Ave. D, S.E., Winter Haven
Brown, M. L., Box 3751, Orlando
Brown, Rue L., Naco Fertilizer Co., Ft. Pierce
Bruce, Hugh, P. O. Box 2251, Palm Beach
Bruton, Gene L., 4150 E. 56th St., Cleveland, Ohio

Bryan, Donald S., Lake Garfield Nurseries Company, Bartow
Bryan, R. L., Lake Garfield Nurseries Company, Bartow
Bryant, J. H., Box 10188, Tampa
Buckhannon. W. H., Soil Conservation Service. Gainesville
Bulkley, John M., Box 846, West Palm Beach
Burgess, Raymond H., 2225 N.W. 8th Ct., Gainesville
Burgis, Donald S., Box 2125 Manatee Sta., Bradenton
Burke, R. E., P. O. Box 1314, Winter Park
Burns, Joe D., 1401 Peachtree St., N.E., Atlanta 9, Ga.
Burt, Dr. Evert O., Dept. of Agron., Fla. Agr. Expt. Sta., Gainesville
Busby, Joe N., 1205 S.W. 11th Ave., Gainesville
Bus.o, Alberto M., Calle 16 No. 206, Havana, Cuba
Butler, Alfred F., United Fruit Co., LaLima, Honduras, C. A.
Butts, Don, Florida Fruit & Vegetable Association, 4401 East Colonial Drive, Orlando
Byrom, Mills H., Everglades Experiment Station (U.S.D.A.), Belle Glade
Calderon P., Roberto, Cordoba No. 218-A, Mexico 7 D. F. Mexico
Caldwell, Parker, Foster & Wigginton, P. O. Box 669, Tallahassee
Caldwell, R. E., Soils Dept. Florida Agricultural Experiment Station, Gainesville
Calma, Dr. V. C., Univ. of Philippines, Lugana, P. I.
Camacho, Edilberto, Rubber Plant Indus., U.S.D.A., Turrilba, Costa Rica, C. A.
Campbell, H. C., 207 N. Eola Drive. Orlando
Campbell, John D., 1102 No. Krome Ave., Homestead
Cardoso, Eno de Miranda, US:NA Monte Alegre, Piracicaba, Brazil
Carlisle, V. W., 1119 N.W. 25th Ave., Gainesville
Carlton, R. A., Box 1986, West Palm Beach
Carothers, Charles H., Box 456, Riverside Station, Miami
Carpender, William P., P. O. Box 105, Delray Beach
Carr, Dr. R. H., 2835 Riddle Dr., Winter Park
Carranza, Guillermo L., O'Reilly No. 264, Havana, Cuba
Carrigan, Dr. Richard A., Armour Research Foundation, Chicago 16, Illinois
Cartledge, Raymond H., P. O. Box 7, Cottondale
Caruso, Ing. Joaquin, Avenida-D-de El Pinar, Apartmento n/I, Caracas, Venezuela, S. A.
Carvalho, J. Higno de, Posto de Defesa Sanitaria Vegetal, Maceio, Alagoas, Brazil. S. A.
Case, Dr. Milnor W., Box 789, Melbourne
Castillo, Dr. Pedro M., Ave. Los Lauras No. 7, San Rafael "La Florida," Caracas, Venezuela, S. A.
Causey, J. H., Rt. 3, Box 36-B, West Palm Beach
Chapman, Willis H., North Fla. Expt. Sta., Quincy
Chase, Frank W., Isleworth, Windemere
Cherry, F. E., Route No. 1, Box 652, Fort Lauderdale
Chioetta, Dr. Franco, S. A. Zuccherificio de Sermide, Mantova, Italy
Choate, Rush E., Agr. Eng. Dept., Univ. of Fla., Gainesville
Christie, James R., Box 3751, Orlando
Christie, Dr. Jesse R., Agr. Expt. Sta., Gainesville
Chronister. Borden S., P. O. Box 28, Hopewell, Virginia
Chuidian, Antonio A., Edificio Soriana, Plaza Cervantes, Manila, Philippines
Clark, Bernard, Box 426, Quincy
Clark, Everett, 116 23rd St., W., Bradenton
Clark, Fred A., Agricultural Experiment Station, Gainesville
Clark, K. A., Court House, Sarasota
Clark, Lewis Jesse, 230 Soils Bldg., Plant Ind. Sta., Beltsville,
Clayton, B. S., 119 Maryland Ave., Washington 19, D. C.
Clayton, H. G., Florida Agricultural Extension Service, Gainesville
Cobo, Margarita, Facultad de Ing. Agron., Maracay, Venezuela, S. A.
Codecido, Francisco H., Calle 144, Rio 159 Valencia Edo. Carabobo, Venezuela, S. A.
Coe, Dr. Dana G., Route No. 2, Providence Road, Lakeland
Coe, Donald M., Box 507, Ft. Pierce
Cohen, Gustavo Pinto, Calle Urdaneta-Edificio Coromoto, Apartmento 3, Chacao, Estado Miranda, Venezuela, S. A.
Cohen, Mortimer, Box 3777, Gainesville
Collier, Barrett L., Rm. 20, Old Postal Bldg., Winter Haven
Colter, R. L., P. O Box 830, Lakeland
Colyer, R. A., Colyer Watson, Ltd., Rabaul, New Guinea
Conkling, Frank E., P. O. Box 431, Clewiston
Conkling, W. Donald, Mt. Dora
Connell, James R., Box 188, Bushnell
Contreras, Jesus Efraim, Pro-Patria 9a Calle No. 41, Caracas, Venezuela, S. A.
Cooper, George H., P. O. Box 198, Princeton
Coral Fiber Company, Box 5321, Jacksonville 7

Corbett, M. Kenneth, Plant Path. Dept., Univ. of Fla., Gainesville
Corrie, Dr. Frank Ewart, Kelvingrove-Worsted Lane, East Grinstead, Sussex, England
Corzo, Dr. R. Hernandez, Prosperidad No. 13-B, Mexico 18, D. F., Mexico
Cowgill, Carl F., 205 Lois Avenue, Tampa
Cox, Dr Robert S., Box 37, Belle Glade
Craig, Alan L., Everglades Experiment Station, Belle Glade
Craig, Robert M., Box 3149, Orlando
Crall, Dr. James M., P. O. Box 321, Leesburg
Crawely, Bernhard, P. O. Box 117, Tanga, Tanganyika Territory, British East Africa
Creech, Sara, Belle Glade
Creel, John M., Jr., Flavet 2, Apt. 370C, Gainesville
Crenshaw, Robert C., Howard Fertilizer Co., Box 3028, Orlando
Crump, Dr. J. E., 253 21st St., S.W., Winter Haven
Cruz, Eugenio E., Bureau of Industry, Manila, P. I.
Cruz, O. E., % County Agent's Office, Orlando
Cunha, Dr. T. J., Dept. of Animal Husbandry, College of Agriculture, Gainesville
Cunningham, H. G., Tennessee Corporation, 619-27 Grant Building, Atlanta, Georgia
Cunningham, Dr. I. J., Supt. Wallaceville Animal Research Sta. Private Bag, Wellington, New Zealand
Curtis, B. P., Tenn. Coal & Iron, Fairfield, Alabama
Curtis, R. G., Box 338, Palmetto
Dalmau, Gilberto, Edificio Payret, San Jose y Prado, Havana, Cuba
Danley, Cole, Jr., Box 287, Lake Placid
David, Joffre C., Florida Fruit & Vegetable Association, 4401 East Colonial Drive, Orlando
David, Vincente A. C., General Luna St., Naga City, Philippines
Davidson, J. H., 225 Broadway St., So. Haven, Mich.
Davis, Dr. John F., Soil Science Dept., Michigan State College, East Lansing, Michigan
Day, William A., Box 1139, Bradenton
Dekle, George W., State Plant Board, Gainesville
Del-Cristo, Gonzalo J., 6 No. 209 Sixth Floor, Apt. No. 1, Vedado, Havana, Cuba
deLaet, Adolpho, Caixa F 224, Sao Paulo, Brazil, S. A.
DeLeon, Donald, 16 Oviedo Ave., Coral Gables
Delgado, Dr. Enrique, Div. de Estudios Agro. Direccion de Obras de Riego, Ministerio de Obras Publicas, Caracas, D. F. Venezuela, S. A.
Delgado, Macrobio, Div. de Suelos, I.N.A., Maracay, Venezuela, S. A.
Demko, Dr. Charles, Box 203, Altoona
Demko, C. W., Box 203, Altoona
DeMoya, P. P., 740 Avon Rd., West Palm Beach
Dempsey, Charles, P. O. Box 1480, Sarasota
Dempsey, J. M., Box 6217, West Palm Beach
Denn, E. K., Apartado 3816, Caracas, Venezuela, S. A.
Dennison, Dr. R. A., Hort. Dept., U. of Fla., Gainesville
DeRojas, Dr. Augustin J., Oficios 452, Havana, Cuba
Deschamps, Ignacio, Instituto Mexicano de Investigaciones Tecnologicos, Legaria 694, Mexico 10, D. F.
Deschapelles, Luis, Edificio Payret, Havana, Cuba
deSola, Francisco, San Salvador, El Salvador, C. A.
Deszyck, Edward J., Citrus Expt. Sta., Lake Alfred
Dewey, George I., 8009 Glenside Drive, Takoma Park 12, Maryland
Diaz, Ing. Agr. Edgar Valero, Norte 13 No. 54, Caracas, Venezuela, S. A.
Diaz, Jose R. Leon, Urb. Francisco de Miranda Bloque, 8 Apto. B-7, Caracas, Venezuela, S. A.
Diaz Romeu, Roberto, Interamerican Inst. Agr. Sc., Turrialba, Costa Rica, C. A.
Dickey, R. D., P. O. Box 2845, University Station, Gainesville
Dieter, Curtis E., 225 Broadway, South Haven, Mich.
Diettrich, Dr. S. DeR., Language Hall, University of Florida, Gainesville
Director of Agriculture, Georgetown, British Guinea, S. A.
Dixon, W. R., P. O. Box 831, Winter Garden
Doig, John S., 2350 N.W. 19th Ave., Miami 42
Doreste, Ernesto, Paleo a Ceiba 34, Caracas, D. F., Venezuela, S. A.
Dovell, J. E., Peabody Hall, Univ. of Fla., Gainesville
Dreher, Paul A., 727 Penn Street, West Palm Beach
Driggers, A. G., Box 426, Quincy
Driscoll, Paul J., Box 333, Clermont
Drosdoff, Dr. Matthew, % American Embassy, Lima, Peru, S. A.
Drummond, T. R., P. O. Box 131, San Juan Capistrano, California
Dryer Jr., Joe, North American Fiber Co., Radiocentro No. 418, Havana, Cuba
Dun, Walter A., Jr., Howard Fertilizer Co., Box 3028, Orlando

Duncan, David B., College of Agriculture, Gainesville
Dunlap, Richard C., Box 668, Hialeah
Dunscombe, C., P. O. Box 1251, Stuart
DuPuis, John G., Jr., Box W, Little River Station, Miami
Early, Charles E., 416 Palmer Bank Bldg., Sarasota
Eastern States Farmers' Exchange, P. O. Box 1482, Springfield, Massachusetts
Eaton, Dewitt, Box 4440, Sarasota
Eaton, Frederik S., 151 Court St., New Haven 10, Conn.
Echavarria, Dr. Camilo, Calle 50 No. 49-68, Medellin, Colombia, S. A.
Eddins, Dr. A. H., Agr. Expt. Sta., Hastings
Eddy, Dr. Walter H., 5610 Georgia Ave., West Palm Beach
Edsall, Robert S., 1828 28th Avenue, Vero Beach
Edson, Seton N., Soils Dept., College of Agriculture, Gainesville
Edwards, William G., 3900 Ibis Dr., Orlando
Edwardson, Dr. John R., 306 Newell Hall, Univ. of Fla., Gainesville
Elliott, I. L., New Zealand Dept. of Agriculture, Hamilton, New Zealand
Embrey, Webb, Chamber of Commerce, St. Joseph 2, Missouri
Engelman, Herbert G., Box 127, Boynton Beach
Enns, W. G., Box 840, Winter Haven
Eno, Dr. Charles F., Soils Dept., Univ. of Fla., Gainesville
Enzor, Joe K., Jr., Box 1304, Winter Haven
Epting, J. Claude, Box 1907, Orlando
Erck, George H., Box 448, Leesburg
Ervine, F. W, R.F.D. No. 1, Pottstown, Pennsylvania
Erwin, Thomas C., 744 South Bumby St., Orlando
Essig, J. C., RR 1, Box 349, Homestead
Estrada, Dr. Antonio J., Div. de Estudios Agro., Direc. de Obras de Riego, Ministerio de Obras Publicas, Caracas, D. F., Venezuela, S. A.
Evans, J. W., Wheeler Fertilizer Co., Oviedo
Everett, Paul, Agr. Expt. Sta., Gainesville
Eyman, David H., 810 S. Lakeland Dr., Sebring
Farmer, R. H., Coronet Phosphate Co., Plant City
Fawsett, C. F., Jr., Box 186, Orlando
Felix, Dr. E. L., Plant Pathology Dept., Agricultural Experiment Station, Knoxville, Tennessee
Fernandez, Carlos E., Instituto Inter-Americano de Ciencias Agr., Turrialba, Costa Rica, C. A.
Ferragut, Casto, Calle Primera esq. H., Rancho Boyeros, Cuba
Fifield, W. M., Provost, 107 Floyd Hall, Gainesville
Fiskel, Dr. J. G. A., Asst. Biochemist, Florida Agricultural Experiment Station, Gainesville
Fletcher, Fred W., Dow Chemical Co., Midland, Mich.
Flipse, Dr. M. Jay, M.D., 550 Brickell Avenue, Miami 32
Florida Favorite Fertilizer, Inc., Lakeland
Florida Nursery & Landscape Co., Box 97, Leesburg
Florida Seed and Feed Co., Box 56, Ocala
Florida State Chamber of Commerce, Hildebrandt Bldg., Jacksonville
Fohrman, M. H., Bureau of Dairy Ind., Beltsville, Md.
Forbes, R. B., U. S. Regional Pasture Research Lab., State College, Penn.
Ford, Harry W., Box 1122, Lake Alfred
Ford, Robert N., 9 Majorca Avenue, Coral Gables
Forman, H. M., P. O. Box 399, Fort Lauderdale
Forsee, Dr. W. T., Jr., Everglades Experiment Station, Belle Glade
Fortson, R. Malcolm, 720 Florida Title Bldg., Jacksonville
Fosgate Growers Coop., P. O. Box 2673, Orlando
Foster, C. W., 421 S.W. 10th St., Ft. Lauderdale
Frederick, John, Florida East Coast Fertilizer Company, Homestead
Freeman, Ralph Egbert, Box 493, Belle Glade
Frenzel, Arnoldo, C. Postal 357, Curitiba, Pasana, Brazil, S. A.
Friedmann, Walter J., Jr., P. O. Box 2537, Mulberry
Gallagher, Vincent W., 13 N.E. 13th Street, Delray Beach
Gallatin, M. H., Box 2160, Norfolk, Va.
Galli, Ferdinando, Fitopatologia e microbiologia Escola Superior de Agricultura, Piracicaba, S. P., Brazil, S. A.
Gammon, Dr. Nathan, Jr., Soils Dept., Agricultural Experiment Station, Gainesville
Gangstad, Dr. Edward O., Texas Research Foundation, Renner, Texas
Garcia, Dr Enzo Lawner, Div. de Estudios Agro., Direc. de Obras de Riego, Ministerio de Obras Publicas, Caracas, D. F., Venezuela, S. A.
Gardner, David, Room 5206 South Bldg., Washington, D. C.
Gardner, Dr. F. E., 415 North Parramore Street, Orlando
Garman, Dr. Willard H., American Plant Food Council, Inc., 910 17th St., N.W., Washington 6, D. C.
Garman, William L., 2010 So. Utica, Tulsa 4, Okla.

Gee and Jensen, 309 Comeau Building, West Palm Beach
Genung, William G., Everglades Experiment Sta.ion, Belle Glade
George, H. E., Box 26, Palmetto
Geraidson, Carroll M., Gulf Coast Experiment Station. Bradenton
Gilbert, Frank A., Batelle Memorial Inst., 505 King Ave., Columbus 1, Ohio
Gildea, Ray Y., Jr., 1229 S.W. 9th Road, Gainesville
Gillis, Marvin B., International Min. & Chem. Corp., 5401 Harrison St., Skokie, Illinois
Gilman, R. L., Room 10, Newell Hall, Univ. of Fla., Gainesville
Gist, M. N., P. O. Box 913, Leesburg
Givens, Lawrence S., 153 McClean St., Decatur, Georgia
Glenn, W. W., Box 530, Marianna
Goldweber, Seymour, Box 1015, So. Miami
Gomez, R., Ing. Godivell, V. Garzon 230, Santiago de Cuba, Cuba
Gonzales, Dr. Antonio, Lealtad 622, Havana, Cuba
Good, Joseph M., Jr., Soils Dept., University of Florida, Gainesville
Goolsby, Louis C., Wayside Press, P. O. Box 443, Gainesville
Gordon, Harry, 83 Stenhouse Dr., Edinburgh 11, Scotland, United Kingdom
Gosdin, G. W., Box 599, Jacksonville
Goss, John S., Box 2429, West Palm Beach
Grahn, Walter G., Box 1273, Tampa 1
Grant, Dr. T. J., U. S. Sub-Tropical Fruit Field Sta., 415 N. Parramore St., Orlando
Graw, LaMonte, Florida Fruit & Vegetable Association, 4401 East Colonial Drive, Orlando
Gray, Bruce, Rt. 1, East Palatka
Green, Dr. Victor E., Jr., Everglades Experiment Station, Belle Glade
Greenwood, Leonard D., Box 84, Frostproof
Griffin, C. C., Griffin Nurseries, P. O. Box G, Branford
Griffiths, J. T., P. O. Box 1304, Winter Haven
Groebe, R. H., P. O. Box 1429, Cocoa
Grossenbacher, J. G., Plymouth
Gumz, Elmer, 736 Country Club Lane, South Bend, Indiana
Gumz, Richard, Drawer 158, North Judson, Indiana
Gunn, Colin, Soil Conservation Service, P. O. Box 162, Gainesville
Gunter, Dr. Herman, State Geologist, Tallahassee
Guzman, Dr. V. L., Everglades Expt. Sta., Belle Glade
Hadley, Frank E., P. O. Box 2142, San Juan, Puerto Rico
Hale, Roger H., Route 1, Palmetto
Hall, Chesley B., Hort. Dept., Agr. Expt. Sta., Gainesville
Hamilton, Dr. Max G., 268 Daniel Drive, Clemson, S. C.
Hammar, Dr. H. E., Central Chemical Laboratory, U.S.D.A., 606 Court House, Shreveport, La.
Hammond, Dr. Luther C., Soils Dept., University of Florida, Gainesville
Hancock, Mrs. Robert D., Howard Fertilizer Co., Box 3028, Orlando
Hanks, Dr. Robert W., Citrus Expt. Sta., Lake Alfred
Hanson, W. D., Plant Industry Sta., Beltsville, Md.
Hardin, Walter S., Box 660, Bradenton
Hardman, L. E., Box 11308 Produce Sta., Tampa 10
Harris, B. J., Jr., Box 209, Sebring
Harris, Dr. Henry C., Agronomy Dept., Florida Agricultural Experiment Station, Gainesville
Harrison, Dalton, Everglades Expt. Sta., Belle Glade
Harrison, H. O., Box 352, DeFuniak Springs
Har.t. E. W., P. O. Box 1025, Avon Park
Hartwig, Lester H., Union Springs, Ala.
Hasty, A. H., 1503 N.W. 16th Terrace, Gainesville
Hayman, W. P., County Agent, P. O. Box 711. Bartow
Hayslip, Norman C., P. O. Box 1198, Fort Pierce
Hemenway, Alan, 200 7th St., N.W., Winter Haven
Henderson, Clarence, Wheeler Fertilizer Co.. Oviedo
Henderson, J. R., Extension Service, Coll. of Agr., Gainesville
Hendrie, James Harold, 4555 S.W. 2nd St., Miami
Henriquez, Edward G., P. O. Box AG, Vero Beach
Hendrixson, L. M., 44904 Road 136, Orange Cove, Calif.
Hepler, Paul R., Univ. of Maine, Orono, Maine
Herbert, J. H., Jr., 1318 S.W. 14th St., Gainesville
Herize-Ponce, Dr. Oscar, Div. de Estudios Agro. Direc. de Obras de Riego, Ministerio de Obras Publicas, Caracas, D. F. Venezuela, S. A.
Herr, Ben, Box 1425, West Palm Beach
Herren, Norman A., The Collier Company, Everglades
Herring, J. K., Atlantic Coast Line Railroad, Gainesville
Hester, Dr. Jackson B., Agric. Research Laboratories, Elkton, Md.
Heth, Sherman C., J. I. Case Co., 700 State St., Racine. Wisconsin
Higginbottom, Dr. Sam, Babson Park

Hill, Boyd H., Municipal Bldg., Room 117, St. Petersburg
Hill, Jefferson P., P. O. Box 4459, Jacksonville
Hillbrath, Arthur, 219 Dyer Ave., West Palm Beach
Hills, Walter A., Route No. 1, Box 106, John's Island, South Carolina
Hobbs, Frank, 305 Morgan St., Tampa
Hodges, Dr. Elver M., Range Cattle Experiment Station, Ona
Hodges, M. A. Colonia Coleman, San Pedro Sula, D. D., Honduras, C. A.
Hodnett, J. Victor, P. O. Box 351, Winter Haven
Hoffman, J. A., Lutz
Hogan, Ivey W., P. O. Box 1257, Ft. Lauderdale
Holcomb, E. D., Jr., Growers Fertilizer Coop., Lake Alfred
Holden, B. Heath, Sunland Grove Development Co., Route No. 2, Box 486, Homestead
Holland, Frank, Florida Agricultural Research Institute, P. O. Box 392, Winter Haven
Holland, H. H., Atlantic Coast Line Railroad Company, Fort Myers
Holman, Howard P., P. O. Box 2268, Hollywood
Holmes, Jack O., P. O. Box 417, Tampa
Holstein, Miss Helen D., State Home Dem. Office, Tallahassee
Holtsberg, H. I., 132 North 12th Street, Fort Pierce
Horder, Edward J., Gen. Del., Fairhope, Ala.
Horn, Granville C., Soils Dept., Agri. Exp. Station, Gainesville
Horn, H. H., P. O. Box 1, Miami Beach
Horner, Dr. E. S., Agron. Dept., Agr. Expt. Sta., Gainesville
Horton, Miss Sara, Rt. 3, Box 36-B, West Palm Beach
Hoveland, Carl S., Agron. Dept. Univ. of Fla., Gainesville
Howard, Frank L., P. O. Box 996, Winter Haven
Howard, J. D., Howard Fertilizer Co., Box 3028, Orlando
Howard, R. M., Howard Fertilizer Company, Box 3028, Orlando
Howard, R. M., Jr, Howard Fertilizer Co., Box 3028, Orlando
Howe, David O, Box 43, Renner, Texas
Hoy, Nevin D., P. O. Box 348, Coconut Grove, Miami 33
Huff, Norman V., P. O. Box 5, Winter Haven
Hull, Dr. Fred H., Agron. Dept., Agricultural Experiment Station, Gainesville
Hundertmark, B. W., U. S. Sugar Corporation, Clewiston
Hunter, Dr Albert S., Soils Dept., Oregon State College, Corvallis, Oregon
Hunter, J. H., P. O. Box 84, Albany, Georgia
Hunter, James R., Apartado 1649, San Jose, Costa Rica, C. A.
Hunter, W. P., R. 2, Box 61, Alachua
Hurst, Wilbur, Plant Industry Station, Beltsville, Md.
Husmann, Dr. Werner, 646 Seminole Dr., Winter Park
Hutton, Dr. Curtis E., Rt. 3, Jay
Imperial Agricultural Corporation, 801 Windsor Street, Hartford, Connecticut
Inerarity, Jose Garcia, P. O. Box 47, Placetas, Las Villas, Cuba
International Min. & Chem. Corp., Box 2567, Mulberry
Ippisch, F. J., 10C. 2-56, Guatemala City, C. A.
Iznaga, Ferdinand, Payret Bldg., Havana, Cuba
Jackson, R. D., Jackson Grain Company, Tampa
Jackson, Winston J., P. O. Box 927, Kingsport, Tenn.
Jacob, Dr. Kenneth D., Plant Industry Station, U.S.D.A., Beltsville, Md.
Jacobsthal, Gustavo W., 4a Calle 1-49, Guatemala City, Guatemala, C. A.
James, George M., Box 561, Columbia, Tenn.
Jamison, F. S., Hort. Dept., Univ. of Fla., Gainesville
Jarvis, Tom, Box 408, Clermont
Jeffers, Dr. Robert L., Rt. 3, Jay
Jelenszky, Ing. Carlos F., Edificio Payret, San Jose y Prado, Havana, Cuba
Jelks, Miss Ruth, Venice
Jernigan, W. P., U. S. Sugar Corporation, Clewiston
Johnson, B. V., Box 16, Altoona
Johnson, Charles M., 311 S. Willis Ave., Champaign, Ill.
Johnson, J. C., 16203 1st St., E., St. Petersburg
Johnson, J. Earl, Box 61, Gainesville
Johnson, John W., Jr., % American Embassy, Havana, Cuba
Johnson, Lamar, P. O. Box 972, Lake Worth
Johnson, R. S., 1811 Hansen, Sarasota
Johnson, V. C., Route 1, Box 9, Dinsmore
Jones, David W., Range Cattle Experiment Station, Ona
Jones, John P., Army Map Service, 6500 Brooks Lane, Washington 25. D. C.
Jones, Ralph, Drawer 4459, Jacksonville
Jorgensen, Kenneth, Zellwin Farms Co., Zellwood
Jorgensen, M. C., P. O. Box 233, Ruskin
Jove, Dr. Jesus E., Div. de Estudios Agro., Direc. de Obras de Riego, Ministerio de Obras Publicas, Caracas, D. F., Venezuela, S. A.
Juantorena, Julian, Central Gomez Mena, San Nicolas, Cuba

Kaiser, Karl M., 4504 Windsor Lane, Bethesda, Md.
Kaleel, Wm. C., 146 Second St., N., St. Petersburg
Kallio, Aruo, P. O. Box 1003, Alaska Agr. Expt. Sta., College, Alaska
Kantor, Samuel, A Street, Tel Aviv, Hakiryah, Israel
Kaspar, P. E., Sherwin-Williams Co., P. O. Box 906, Tampa
Katz, Alfred, 71 East 77th St., New York, 21, New York
Kauffman, John H., P. O. Box 906, Eustis
Keenan, Edward T., Keenan Laboratories, Frostproof
Keilhauer, Victor, 6A Calle Oriente No. 14, San Salvador, C. A.
Kelbert, David G. A., Box 678, Manatee Sta., Bradenton
Kelly, Earl M., P. O. Box 338, Palmetto
Kelly, William H., Box 446, Quincy
Kelsey City Landscape & Nurseries Company, Inc., Palm Beach
Kelsheimer, Dr. E. G., Box 678, Manatee Sta., Bradenton
Kendrick, W. H., P. O. Box 338, Palmetto
Kern, W. Robert, Jr., 1100 S.W. 2nd Ave., Miami
Kidder, R. W., Everglades Expt. Sta., Belle Glade
Khan, Sharif Ahmad, Dist. Agric. Officer, Bahawalnagar, W. Pakistan
Khanna, K. L., Dir. Sugarcane Res. & Dev., Pusa, Bihar, India
Kieser, Charles F., 521½ S. Andrews Ave., Ft. Lauderdale
Kijewski, Dr. Jan, Div. de Estudios Agro., Direc. de Obras de Riego, Ministerio de Obras Publicas, Caracas, D. F., Venezuela, S. A.
Killinger, Dr. G. B., Apartado 1649, San Jose, Costa Rica
Kimball, D. A., R. R. 1, Simcoe, Ontario, Canada
Kime, C. D., Jr., Route No. 1, Box 325, Winter Haven
Kime, C. D., Sr., Box 232, Fort Pierce
Kincaid, Dr. R. R., North Florida Experiment Station, Quincy
King, A. D., Box 8462, Lantana
King, Battey, Box 482, Naples
Kipnis, Dr. Walter Seth, Box 235, Orange, New Jersey
Kirk, Dr. W. Gordon, Range Cattle Experiment Station, Ona
Kirkland, Robert O., American Cyanamid Co., Brewster
Kliman, Dr. Stephen, 2809 N. Grant Blvd., Milwaukee 10, Wis.
Knight, T. W., Pahokee
Knoblauch, Dr. H. C., Rt. 1, Box 471, Vienna, Virginia
Kolterman, D. W., E. I. duPont de Nemours & Co., Wilmington, Del.
Koo, Dr. Robert C. J., Citrus Expt. Sta., Lake Alfred
Kortlevei, A., N. Z. Voorburgwal 162, Amsterdam-C, Holland
Krall, J. L., Willow Brook Farms, Catasauqua, Pennsylvania
Krangel, A., 1511 Fox Bldg., Philadelphia 3, Pa.
Kressler, James F., 2575 Cordova, Vero Beach
Kretschmer, Dr. Albert E., Jr., Indian River Field Lab., Fort Pierce
Kruse, Albert, P. O. Box 157, Belle Glade
Kruse, Frank, P. O. Box 157, Belle Glade
Kunz, John A., 2331, N.W. 15th Street, Miami
Kurtz, Dr. Touby, Agronomy Department, University of Illinois, Urbana, Illinois
Lagasse, F. S., Box 2817, Gainesville
LaHacienda Company, Inc., 20 Vasey St., New York 7, New York
Lamarche, Rene, 263 Alle Verte, Ghent, Belgium
Lamrock, Jack C., Dept. of Agr., Port Moresby, New Guinea
Lanata, Gabriel, Arenales 2037, Lima, Peru
Lander, Donald W., P. O. Box 155, Everglades
Lang, Prof. A. L., Dept. Agron., Agr. Expt. Sta., Urbana, Ill.
Larned, Miss Joan B., Howard Fertilizer Co., Box 3028, Orlando
Larrazabal, Eduardo, LaFlorida, Calle Coello, Qta., Esperanza, Caracas, Venezuela, S. A.
Larsen, Otto, P. O. Box 1334, Clewiston
Larson, David J., P. O. Box 162, Hinsdale, Illinois
Lassiter, R. E., Jr., Box 1304, Winter Haven
Lawhon, Rex, 407 S.E. 2nd St., Gainesville
Lawrence, Fred P., Agric. Ext. Serv., Gainesville
Lee, C. S., Oviedo
Leetun, O. C., American Agric. Chem. Co., 50 Church St., New York 7, N. Y.
Leide, Rudolph E., Box 372, Matteson, Illinois
Leighton, Bruce G., Box 351, Stuart
Leighty, Ralph G., 1330 N.W. 17th St., Gainesville
Leon, Oswaldo Hernandez, Barrio Sta., Ana Calle Madrid No. 27, Maracay, Venezuela, S. A.
Leonard, Dr. Chester D., Citrus Experiment Station, Lake Alfred
Leonard, George V., Pres., Wetumpka Fruit Company, Hastings
LePage, Ramon, 3er, Callejon El Carmen Quinta Los Muchachos, Los Chorras, Edo. Miranda, Venezuela, S. A.
Leuze C., Elizabeth, P. O. Box 304F6, Mexico 18, D. F., Mexico

Lewis, Charles D., 70 Pine Street, New York 5, New York
Lewis, Olin C., 628 N.E. Second Street, Gainesville
Lewis, Victor W., Atlantic Coast Line Railroad Company, Wilmington, North Carolina
Lindabury, Robert E., 3301 McGregor Blvd,. Ft. Myers
Linde, Dieter, R.F.D. No. 2, Nottingham, Pennsylvania
Lins, E. W., American Fruit Growers, P. O. Box 1302, Fort Pierce
Lipscomb, R. W., Box 504, Marianna
Lira, Manuel Herrera, Sta. Rosa a San Isidro No. 9, Inebrada Honda, Caracas, Venezuela, S. A.
Llano, Manuel del, Facultad Nacional de Agron., Apto. Aereo 567, Medellin, Colombia, S. A.
Llewellyn, W. R., 1102 N. Krome Ave., Homestead
Lockett, Norwood A., Box 358, Leesburg
Logan, J. H., P. O. Box 540, Clearwater
Lomelin, Juan Manuel, P. A. de los Santos 43, Mexico D. F., Mexico
Long, E. H., 2030 43rd St., S., St. Petersburg
Lord, John F., United Fruit Company, Banes, Cuba
Lorz, Dr. A. P., Agr. Expt. Sta., Gainesville
Low, Alexander, 155 East 44th Street, New York 17, New York
Lowman, J. W., Meramac Minerals, Inc., P. O. Box 8615, Tampa
Lowry, Wayne H., Int. Harvester Co., 180 N. Mich. Ave., Chicago, Ill.
Lucas, Glenn H., P. O. Box 3272, Tampa
Lucas, Dr. Robert E., Soil Science Dept., Agr. Expt. Sta., East Lansing, Mich.
Lugo, Dr. Julio J., Div. de Estudios, Dir. de Obras de Riego, Min. de Obras Publicas, Caracas, D. F., Venezuela, S.A.
Lundberg, Dr. Ernest C., 2609 Hargill Dr., Orlando
Lundy, H. W., Suwannee Valley Expt. Sta., Live Oak
Lyerly, W. A., Jr., American Agr. Chem. Co., Pierce
Lynch, S. J., Box 1015, So. Miami 43
Lynde, Hunter, 1628 San Marco Blvd., Jacksonville 7
McBride, J. N., Seaboard Air Line Railroad Co., Savannah, Georgia
McCaleb, John E., Range Cattle Sta., Ona
McCallum, Don, 1115 Penn Ave., Pittsburgh 22, Pa.
McCallum, J. B., Box 516, Hastings
McCartney, E. A., Box 310, Tampa
McCloud, Dr. D. E., Agron. Dept., U. of Fla., Gainesville
McCollum, Samuel H., Box 387, Ocala
McConnell, D. F., 711 S.W. 28th Road, Miami
McCraney, John M., 414 Bryan St., Douglas, Ga.
McCubbin, Dr. Earl N., Fla. Expt. Sta., Hastings
McElwee, Dr. E. W., Agr. Ext. Serv., Gainesville
McKinney, Dr. R. S., U.S.D.A., Post Office Building, Bogalusa, La.
McLain, L. Rogers, 2702 Jetton Avenue, Tampa
McLane, W. F., Box 310, Tampa 1
McMichael, Frank P., Box 1314, Tampa
McMullen, P. R., Box 517, St. Augustine
McPeck, John K., 500 So. Orange St., Sebring
McPherson, Prof. W. K., Dept. Agr. Economics, University of Florida, Gainesville
McSwiney, Daniel J., 401 S.W. 14th Ave., Ft. Lauderdale
Macaulay, Mrs. Alex G., 1039-1041 Central Ave., St. Petersburg
Macfie, A. P., P. O. Box 1298, DeLand
Mackenzie, Donald, William Stone Sons, Ltd., Ingersoll, Ontario, Canada
Madrid, Carlos, Apartado 478, Lima, Peru
Magie, Dr. Robert O., Box 2125 Manatee Sta., Bradenton
Mahoney, C. H., 1133 20th Street, N.W., Washington 6, D. C.
Malcolm, Dr. J. L., Sub-Tropical Experiment Station, Homestead
Mallen, Leonard R., 400 Jarvis St., Toronto, Canada
Maltby, H. E., Palatka
Manchester, Dr. R. G., 17 S.W. 4th Ave., Gainesville
Mann, F. S., 717 Wilkie St., Dunedin
Manning Paper Company, John A., Troy, New York
Marfari, Ricardo T., Bureau of Soil Conservation, Florida Street, Manila, Philippines
Martin, Joel Mann, 1521 Duncan St., Key West
Martin, John W., Box 125, Crescent City
Marwani, Kadar, djalan Langsat V No. G (D2), Kotabara Kebajoran, Djakarta, Indonesia
Masek, John, Apopka
Maxwell, Lewis S., Jackson Grain Company, P. O. Box 1290, Tampa
Mayeux, Herman S., Box 658, Jacksonville
Mayo, Nat, Inspection Bur., Dept. of Agr., Mayo Bldg., Tallahassee
Maza, Manuel, Edificio Payret, San Jose y Prado, Havana, Cuba
Means, Geo. C., Wheeler Fertilizer Co., Oviedo
Medina, Julio Cesar, Caixa Postal, 28, Campinas, Brazil, S. A.

Medina, Dr. Luis J., Apartado 4562, Maracay, Venezuela, S. A.
Medlin, Quentin, Box 67, Inverness
Meloy, R. F., Box 77, Immokalee
Menninger, Edwin A., Stuart Daily News, Inc., Stuart
Mercer, M. T., P. O. Box 181, Coral Gables
Middleton, Dr. H. E., U.S.O.M., APO676, % P. M., New York, N. Y.
Miller, Earl C., 1237 N.E. 14th Ave., Ft. Lauderdale
Miller, John T., Rt. 3, Box 573, Albany, Georgia
Miller, Dr. Ralph L., Plymouth Citrus Growers Association, Plymouth
Miller, Robert G., 1117 Orange Avenue, Ft. Pierce
Milligan, J. Wiley, 330 Dartmouth Dr., Lake Worth
Minton, E. J., Drawer 270, Ft. Pierce
Mitchell, Dr. R. L., Macauley Institute of Soil Research, Craigiebuckler, Aberdeen, Scotland
Mixon, Aubrey C., 402 Newell Hall, Gainesville
Montelaro, James, Minute Maid Corp., Plymouth
Moore, Dr., Castles W., 311 Blount Bldg., Ft. Lauderdale
Moore, Dr. W. D., Old Plantation Field Lab., 5305 S.W. 12th St., Ft. Lauderdale
Morales, Jose, Apartado 83, Cruces, Las Villas, Cuba
Morcock, J. C., Jr., 133 Carnegie Way, N.W., Atlanta 3, Ga.
Morreo, Miguel A., AVDA. Principal, URB, LaCastellana Qta., Merzuka-Chacao Estado Miranda, Venezuela, S. A.
Morris, R. Henry III, Eastern Regional Research Laboratory, Philadelphia 18, Pa.
Morris, Robert N., Rt. 6, Box 514, Tampa 4
Morrison, D. Dale, 367 N. Orange, Orlando
Morse, Bill, Box 372, Kissimmee
Morton, H. G., 101 Pearl Ave., Sarasota
Mossbarger, H. I., 1001 82nd Street Terrace, Miami
Mount Dora Growers Cooperative, Mount Dora
Mountain Lake Corporation, P. O. Box 832, Lake Wales
Mounts, M. U., County Agent, Rt. 3, Box 36-B, West Palm Beach
Mourkides, G. A., 17 Pasteur St., Thessaloniki, Greece
Mowry, Harold, % American Embassy, San Jose, Costa Rica, C. A.
Muhr, Gilbert R., Inst. of I. A. A., Ciudad Trujillo, Dominican Republic
Mullen, Harris H., 1306 Grand Central Avenue, Tampa
Muller, Dr. Albert S., Floyd Hall, U. of Fla., Gainesville
Murphy, Lionel M., 1948 Bahia Vista St., Sarasota
Mustard, Dr. Margaret Jean, University of Miami, P. O. Box 1015, South Miami
Myers, A. A., Wheeler Fertilizer Company, Oviedo
Myers, Forrest E., Agricultural Extension Service, University of Florida, Gainesville
Myers, J. Mostella, Agr. Eng. Dept., Univ. of Fla., Gainesville
Myhre, Donald L., Potato Lab., Hastings
Nall, W. C., P. O. Box 7188, Clewiston
Naranjo, Celso, Apartado 4608, Maracay, Venezuela, S. A.
Nation, Hoyt A., Box 3145, Greenville, Mississippi
National Cotton Council, P. O. Box 9905, Memphis 12, Tennessee
Neal, Dr. W. M., Rt. 6, Box 970, Tampa
Neenan, Michael, Johnstone Agriculture College, Wexford, Ireland
Neff, Arthur L., R. 3, Box 231, Sarasota
Neff, S. F., Security Mills, Tampa
Neller, Dr. J. R., Soils Dept., Agricultural Experiment Station, Gainesville
Nelson, D. E., Box 175, Hialeah
Nelson, Elton G., U.S.D.A., Plant Industry Station, Beltsville, Md.
Nelson, G. M., P. O. Box 303, Melbourne
Nelson, Roy O., Rt. 1, Box 333, Homestead
Newhouse, John, South Bay
Nielsen, C. S., Botany Dept., Fla. State Univ., Tallahassee
Nix. E. M., Box 26, Jacksonville
Nobles, J. E., Jr., P. O. Box 246, Fort Pierce
Noer, O. J., Sewerage Commission, Milwauke 1, Wisconsin
Normile, Hubert C., 101 Tampa Ave., Melbourne
Norris. R. E., P. O. Box 334, Tavares
Northen, A. C., Box 1156, Tampa
Nunez, Jose I., Div. de Suelos, I.N.A., Caracas, Venezuela, S. A.
Nutter, Dr. Gene C., Agricultural Experiment Station, Gainesville
Ochse, Dr. J. J., 25 Campina Ct., Coral Gables
O'Kell, George S., 902 Biscayne Building, Miami
O'Kelley, E. B., Atlantic Coast Line RR Co., Jacksonville 3
Olds, Jerome, Organic Gardening & Farming, 6th & Minor Sts., Emmaus, Pa.
O'Neil, John, American Cyanamid Company, Brewster
Oropez, Hernan, Div. de Fitotecnia, I.N.A., Maracay, Venezuela, S. A.
Orr, James L., Florida Conservation School, Box 326, LaBelle

Ortega, Dimas A., AVDA, Prin. San Agustin del Sur No. 2, Caracas, Venezuela, S. A.
Overman, Amegda J., Box 2125, Bradenton
Owen, W. C., United States Sugar Corporation, Clewiston
Owen, W. E., P. O. Box 4459, Jacksonville 1
Oxford, James T., Box 1346, Cocoa
Ozaki, Dr. Charles, Everglades Expt. Sta., Belle Glade
Ozaki, Dr. Henry, Plantation Field Lab., Ft. Lauderdale
Pabst, William F., Jr., 48 Mayo Rd., Wellesley, Massachusetts
Padilla, Dr. Gustavo, Div. de Est. Agro., Dir. de Obras de Riego, Min. de Obras Publicas, Caracas, D. F., Venezuela, S. A.
Padilla, Juan F., 10 de Octubre No. 305, Havana, Cuba
Padilla, Pedro, Vargas a Bolivar No. 7, San Augustin del Norte, Caracas, Venezuela, S. A.
Palmer, Mrs. G. K., 5063 Dartmouth Ave., N., St. Petersburg
Pancoast, J. Arthur, Panuleta Farms, Uleta
Park, F. D. R., 1301 Court House, Miami 32
Parker, C. H., 1641 7th St., S.W., Winter Haven
Parker, Ed M., 412 Candler Bldg., Atlanta, Ga.
Parker, Rufus B., 3638 Day Ave., Coconut Grove
Parks, Dr. R. Q., Grace Chemical Co., Memphis 1, Tenn.
Parnell, Sidney B., P. O. Box 1586, Fort Myers
Pate, Dr. James B., Everglades Experiment Station, U.S.D.A., Belle Glade
Patrick, Dr. Roger, Box 403, Winter Haven
Pearson, Dr. R. W., Bureau of Plant Industry, Soils & Agric. Engineering, Auburn, Alabama
Penalver, Dr. Jose Luis, Div. de Est. Agr. Dir. de Obras de Riego, Min. de Obras Publicas, Caracas, D. F., Venezuela, S. A.
Pendleton, Dr. Robert L., % Kasetsart University, Bangkhen, Bankok, Thailand
Perez, Ciria Diaz, Apartado 3950, Caracas, Venezuela, S. A.
Perry, F. S., Agricultural Extension Service, University of Florida, Gainesville
Perry, Henry D., 6200 Perry Drive, W. Hollywood
Peter, Charles, 235 South Main Street, Salt Lake City 1, Utah
Pfeiffer, Dr. E. E., Biochemical Research Laboratory, Spring Valley, N. Y.
Pfizer, Chas. & Co., Inc., Terre Haute, Indiana
Phelps, Ellis K., 426 South Eola Drive, Orlando
Phillips, Charles M., P. O. Box 1400, Clearwater
Pickett, John T., P. O. Box 446, Pahokee
Pierce, William, Box 398, Belle Glade
Pieters, Frans G., 16 Calle 4-32, Zone 10, Guatemala City, C. A.
Piety, P. T., P. O. Box 67, Osteen
Pinckard, Dr. J. A., 55 Marietta St., N.W., Atlanta, Ga.
Platts, Norman W., Rt. 2, Box 678, Ft. Pierce
Poey, Federico, Calzado 854, Vedado, Havana, Cuba
Pol, Rafael, Box 38, Arecibo, Puerto Rico
Popenoe, Hugh, Box 3603, Univ. of Fla., Gainesville
Popenoe, Dr. Wilson, Apartado 93, Tegucigalpa, Honduras, C. A.
Popham, J. R., Jr., Box 75, Osprey
Poskanzer, Esop, 3335 Pickfair Ave., Orlando
Pospichal, Alfred T., Apopka, Florida
Potter, George F., Box 812, Bogalusa, La.
Poucher, J. Lester, 2536 Forbes St., Jacksonville 8
Powers, Dr. W. L., % Oregon State College, Corvallis, Oregon
Pozzo di Borgo, Joseph, 51 Rue de l'Universite, Paris, France
Prange, Edwin, Rt. 2, Box 96, Vero Beach
Pratt, James B., 1419 E. Johns Ave., Haines City
Prewitt, M. M., P. O. Box 1248, Clewiston
Prewitt, W. C., U. S. Sugar Corporation, Clewiston
Price, Col. Terrill E., Rt. 4, Box 190, Gainesville
Pringle, G. W., President, Florida Nursery & Landscape, Leesburg
Pritchett, Dr. William L., Soils Dept., Univ. of Fla., Gainesville
Proctor, Robert C., 15 W. Orange Ave., Lake Wales
Producers Supply, Inc., P. O. Box 387, Palmetto
Puentes, Carlos, Calle A No. 31, Reparto California, Havana, Cuba
Pujals, Pedro P., 5ta No. 256 Vedado, Havana, Cuba
Raeside, J. D., Dept. Sci. Ind. Research, P. O. Box 250, Timaru, New Zealand
Ramos, Dr. R. Menedez, Cooperativa de Agricultores, Puerta de Tierra, San Juan 8, Puerto Rico
Randall, Lawrence E., Colby College, Waterville, Maine
Randolph, John W., Everglades Experiment Station, Belle Glade
Rands, Dr. R. D., Box 31, Route 2, Lake Wales
Raoul, Loring, Sarasota

Rasmussen, Gordon K., 2120 Camden Rd., Orlando
Rath, Ross, Box 21, McIntosh
Ravikovitch, Dr. S., Agric. Research Sta., Rehovot, Israel
Reading, D. Gordon, 7028 Cregier Ave., Chicago 49, Illinois
Reed, Dr. J. Fielding, 710 Mortgage Guaranty Bldg., Atlanta 3, Ga.
Reed, R. R., 4201 Sylvan Ramble, Tampa
Reichel, John H., Box 2035, Palm Beach
Reitz, Dr. Herman J., Citrus Experiment Station, Lake Alfred
Reitz, Dr. Wayne J., Pres., U. of Fla., Gainesville
Remsburg, L. S., P. O. Box 58, Fort Lauderdale
Rennie, Wayland W., 2315 Grubb Rd., Wilmington, Dela.
Retherford, Forest W., 37 10th, Haines City
Reuther, Dr. Walter, Hort. Dept., College of Agr., Univ. of Fla., Gainesville
Reynolds, B. T., Auburndale
Rhoades, W. C., Box 470, Quincy
Riceman, D. S., University of Adelaide, Adelaide, South Australia
Rich, Clarence E., Box 1015, So. Miami
Richards, B. L., Jr., Box 353 Manatee Sta., Bradenton
Richards, Dr. L. A., Box 672, Riverside, California
Richardson, Dr. A. S., 31 Larchmont Drive, Wyoming 15, Ohio
Richardson, E. G., Calumet & Hecla Consolidated Copper Co., 25 S. Main Street, Orlando
Rimoldi, Frank J., 5200 Alhambra Circle, Coral Gables
Rinehart, Dr. James C., U. S. Gypsum Co., 300 W. Adams, St., Chicago, Ill.
Ritty, Paul M., 1029 Santa Anita Road, Orlando
Roberts, A. S., P. O. Box 694, Ocala
Roberts, Mrs. Dorothy C., % Carl Brooks, Box 2, Waterman, Calif.
Robertson, Dr. W. K., Soils Dept., University of Florida, Gainesville
Robinson, W. O., 207 W. Marshall, Falls Church, Va.
Roden, Rex A., P. O. Box 7330, Clewiston
Rodgers, Earl G., College of Agric., Gainesville
Rodriguez, Fremiot, N No. 334 Apt. 8, Vedado, Havana, Cuba
Rogers, Dr. Lewis H., 3013 Patricia Ave., Los Angeles 64, Calif.
Roig, Dr. Juan T., Calle 9, No. 24, Santiago de las Vegas, Cuba
Rolland, E. O., 215 S. Bronough Street, Tallahassee
Rollins, C. F., P. O. Box 981, Clearwater
Romero-Sanchez, Dr. Oscar, Ave. Los Jabillos, No. 10, "La Florida," Caracas, Venezuela, S. A.
Ross, Dr. Harold F., 52 Olga Ave., Wilson 5, Conn.
Rothwell, Donald F., College of Agric., Gainesville
Rounds, Marvin B., 224 N. Mich. Ave., Glendora, Calif.
Roux, Dr. L. L., So. African Embassy, 3101 Mass. Ave., N.W., Washington 8, D. C.
Rowe, W. Mercer, Jr., 601 Trust Co. of Ga. Bldg., Atlanta 3, Ga.
Rozsa, Dr. J. T., National Spectrographic Laboratories, 6300 Euclid Avenue, Cleveland, Ohio
Ruehle, Dr. George D., Rt. 2, Box 508, Homestead
Ruelke, Dr. O. Charles, Dept. of Agron., Univ. of Fla., Gainesville
Ruiz M., Rudolfo, Legaria 694, Mexico 10, D. F., Mexico
Ruprecht, Dr. R. W., Central Fla. Expt. Sta., Sanford
Russell, Ed., Rt. 3, Box 153, Dade City
Rys, Dr. L. J., Rua de Novembro, 575, Curitiba, Parana, Brazil, S. A.
Sachs, Ward H., % U. S. Embassy, New Delhi, India
Sahlberg, Nils, 1200 E. Michigan Ave., Orlando
Salis, Arthur, 4301 Chestnut Street, Philadelphia, Pa.
Savage, C. B., 416 El Prado, West Palm Beach
Scarseth, Dr. George D., 1414 Ravinia Road, Lafayette, Ind.
Schaaf, Harold H., Box 5, Lake Wales
Schieck, DeWitt C., Cordage Institute, 350 Madison Avenue, New York 17, New York
Schlangen, N. A., Box 1167, Rt. 2, Pompano Beach
Schombingk, Ecbert Schulz, Div. de Suelos, I.N.A., Maracay, Venezuela, S.A.
Schroder, Vincent N., Agr. Expt. Sta., Gainesville
Schubart, Dr. F. C., Rt. 4, Box 758V3,
Schumacher, W. C., 9320 Hamlin Ave., Evanston, Ill.
Schupp, Ferd. F., Apartamento 5-A Edificio Aldaz, 8a Aven. y 15 Calle, Guatemala City, Guatemala, C. A.
Schweers, Malcolm, 5555 Sheridan Rd., Chicago, Ill.
Scott, Ed., Clerk of Circuit Court, Everglades
Seale, Charles C., Everglades Experiment Station, Belle Glade
Seipel, Robert B., Blue Ridge Glass Corporation, Kingsport, Tenn.
Selee, Col. R., Forest Park Hotel Apts., St. Louis 8, Missouri
Sell, Dr. O. E., Agricultural Experiment Station, Experiment, Georgia

Senn, Dr. P. H., Dept. of Agronomy, University of Florida, Gainesville
Serviss, George H., G.L.F. Soil Building Service, Terrace Hill, Ithaca, N. Y.
Setzer, Jose, Ing., Rua Maestro Elias Lobo 378, Sao Paulo, S. P., Brazil, S. A.
Shear, Cornelius B., Box 2817, Gainesville
Sheppard, O. H., U. S. Sugar Corporation, Clewiston
Sherwood, Fred H., Calle Montufar No. 9, Guatemala City, Guatemala, C. A.
Shinn, Charles M., Growers' Fertilizer Coop., Lake Alfred
Shirley, Dr. R. L., Dept. Animal Husb., U. of Fla., Gainesville
Shuttleworth, R. G., 1907 K St., N.W., Washington, D. C.
Sieplein, Dr. O. J., 1848 Opechee Drive, Miami 45
Sierra, Francisco A., Escuela Agric. Panamericana, Aptdo. 93, Tegucigalpa, Honduras, C. A.
Silva, Dr. Gabriel, Calle San Rafael No. 20, Manicomio, Caracas, Venezuela, S. A.
Simmons, Dr. Charles S., % U. S. Embassy, Guatemala City, C. A.
Simonpietri, Roberto, Sur 15, No. 50, Caracas, Venezuela, S. A.
Simons, Dr. J. N., Everglades Expt. Sta., Belle Glade
Simonson, Dr. Roy W., 4613 Beechwood Road, College Park, Maryland
Simpson, James S., Columbia Rope Company, 30 South Hunter Avenue, Auburn, New York
Singh, Dalbir, Remmugger Cane & Sugar Co., Plassey, Bengal, India
Singleton, Gray, 125 East Palm Drive, Lakeland
Sites, Dr. John W., Asst. Dir., Agricultural Expt. Sta., Gainesville
Skinner, T. C, Agr. Eng. Bldg., Univ. of Fla., Gainesville
Slough Grove Co., Inc., Box 37, Dade City
Smiley, Nixon, 5985 S.W. Montgomery Dr., Miami 43
Smith, C. Courtland, Howard Fertilizer Co., Box 3028, Orlando
Smith, C. O., Jr., Box 69, Moultrie, Ga.
Smith, Dr. F. B., Dept. of Soils, University of Florida, Gainesville
Smith, French E., Route No. 1, Box 419, Bradenton
Smith, F. M., Howard Fertilizer Co., Box 3028, Orlando
Smith, Leonard C., P. O. Box 1021, Sebring
Smith, Paul F., 2120 Camden Rd., Orlando
Smith, William R., 122 Wall St., Orlando
Snyder, Earl S., Pioneer, Ohio
Solley, Jas. F., Jr., Olin Mathieson Chem. Corp., Baltimore 3, Md.
Soto Villa, Luis J., Descartes 51, Mexico 5 D. F., Mexico
Soule, M. J., Jr., 2120 Camden Rd., Orlando
Sowell, Dr. Grover, Jr., Gulf Coast Expt. Sta., Bradenton
Spears, Helen and Bob, Star Rt. 2, DeLand
Speer, H. L., Pahokee
Speight, K. F., Box 773, Mulberry
Speir, William, 725 S.W. 13th Ave., Ft. Lauderdale
Spelman, H. M., P. O. Box 762, Belle Glade
Spencer, Dr. Ernest L., Gulf Coast Experiment Station, Bradenton
Spinks, Daniel O., Soils Dept., College of Agriculture, Gainesville
Spitzner, Dr. Reinaldo, Rua Recife, 485 Curitiba, Parana, Brazil, S. A.
Stambaugh, Scott U., 9674 N.W. 10th Ave., Miami 50
Stapp, R. T., Fellsmere Sugar Prod. Association, Fellsmere
Starkey, W. P., Mt. Lake, Lake Wales
Staton, Grant, P. O. Box 1764, Orlando
Stein, Fritz, Chosen
Steiner, Dr. G., Div. of Nematology, Plant Industry Station, Beltsville, Maryland
Stephens, John C., 5305 S.W. 12th St., Ft. Lauderdale
Sterling, H. O., Citrus Experiment Station, Lake Alfred
Sterzik, Comdr. R. A., P. O. Box 292, Haines City
Stevens, Wallace, Rt. 2, Box 2030, Ft. Lauderdale
Stevenson, Donald D., Buckeye Cellulose Corp., Foley
Stewart, Dr. Ivan, Citrus Experiment Station, Lake Alfred
Stirling, Walter, R.F.D. No. 1, Fort Lauderdale
Stone, W. H., 1120 Magnolia St., West Palm Beach
Storey, Norman C., Star Route, Box 272, Escondida, Cal.
Stout, G. J., 205 Floyd Hall, Gainesville
Stover, L. H., Box 321, Leesburg
Stuck, Harold D., 29 Chestnut St., Andover, Mass.
Sturrock, James D., Box 2348, Palm Beach
Suggs, George W., Nitrogen Div., Allied Chemical & Dye Corp., 40 Rector St., New York 6, New York
Summers, Dr. T. E., Everglades Expt. Sta., Belle Glade
Summerour, C. W., American Potash Institute, P. O. Box 962, Montgomery 2, Alabama
Swanson, Dr. C. L. W., Connecticut Agricultural Experiment Station, New Haven, Connecticut

Synthetic Nitrogen Products Corporation, 285 Madison Avenue, New York 17, New York
Tabor, Dr. Paul, 845 Bobbin Mill Rd., Athens, Georgia
Tait, W. L., Fla. Citrus Prod. Credit Assn., P. O. Box 695, Winter Haven
Talbott, George M., Florida Fruit & Vegetable Assn., 4401 Colonial Drive, Orlando
Tanner, Dr. Howard A., 150 E. South College St., Yellow Springs, Ohio
Tansill, Robert W., 618 Judson Ave., Evanston, Ill.
Tayloe, Sam D., Rio Farms, Inc., Edcouch, Texas
Taylor, A. L., Div. of Nematology, Plant Industry Sta., Beltsville, Md.
Taylor, J. J., State Chemist, Dept. of Agriculture, P. O. Box 408, Tallahassee
Taylor, N. T., P. O. Box 883, Belle Glade
Taylor, Robert L., 226 Malvern Rd., West Palm Beach
Tempel, E. J., 801 Windsor Street, Hartford, Conn.
Temple, J. C., P. O. Box 494, Ocala
Tennant, Mark R., 1331 DuPont Building, Miami 32
Tennis, Hall, 3709 Bobolink Lane, Orlando
Teran, Manuel J. Mier, Calzada Legaria 694, Mexico 10, D. F.
Thames, Walter H., Jr., Soils Dept., University of Florida, Gainesville
Thomas, Dr. H. Rex, Plant Ind. Sta., Beltsville, Maryland
Thomas, Dr. R. P., 20 North Wacker Drive, Chicago 6, Illinois
Thompson, Dr. Leonard G., Jr., Soils Dept., North Florida Experiment Station, Quincy
Thompson, Vinton N., Vincentown, New Jersey
Thornthwaite, Dr. C. W., Laboratory of Climatology, Rt. 1, Centerton,, Elmer, New Jersey
Thornton, Dr. George D., Soils Dept., College of Agriculture, Gainesville
Thornton, Dr. N. C., Research Dept., Tela Railroad, La Lima, Honduras, C. A.
Thornton, R. P., Thornton & Company, 1145 East Cass Street, Tampa 1
Thornton, S. F., F. S. Royster Guano Company, Norfolk, Virginia
Thorp, Dr. James, Dept. of Geology, Earlham College, Richmond, Indiana
Todd, Howard D., Box 112, Lake Wales
Toll, J. D., Box 310, Tampa 1
Tomasello, Rudolph P., P. O. Box 6156, West Palm Beach
Torres, Emilio Hidalgo, Avda. Prin. de Sebucan No. 17, Los dos Caminos Edo. Miranda, Venezuela, S. A.
Toussaint, Francis B., Everglades Expt. Sta., Belle Glade
Townsend, Dr. G. R., P. O. Box 356, Belle Glade
Tropical Homes and Gardens, Box 804, Coral Gables 34
True, Henry H., 438 N.E. 8th Ave., Ft. Lauderdale
Trumbower, C. K., 5 Revilo Blvd., Daytona Beach
Truog, Dr. Emil, Soils Dept., Univ. of Wisconsin, Madison, Wisc.
Tschudi, T., 56-16 199th Street, Flushing, New York
Tucker, Charles, Box 59, Rt. 1, Brooksville
Tuckett, Norman, Minneola
Turner, B. L., P. O. Box 599, Jacksonville
Underwood, J. K., Univ. of Tenn., Agr. Expt. Sta., Knoxville, Tenn.
Valentine, G. C., P. O. Box 128, Palmetto
Van Arsdall, W. J., Rt. 1, Box 179, Winter Haven
Van Dresser, Cleveland, 327 Dyer Ave., West Palm Beach
Van Horn, M. C., P. O. Box 4459, Jacksonville 1
Van Landingham, E. M., P. O. Box 266, Belle Glade
Van Middelem, C. H., Hort. Dept., Univ. of Fla., Gainesville
Van Natta, Earl S., Jr., Box 2536 Paulstan Ct., Sarasota
Veasey, Harry W., Jr., 3905 E. Broadway, Tampa
Vaughn, H. T., V.-P. and Gen. Mgr., U. S. Sugar Corporation, Clewiston
Venning, Dr. Frank D., Swingle Research Laboratory, American Embassy, Havana, Cuba
Veres, Dr. Michael, 123-25 82nd Ave., Kew Gardens 15, New York, N. Y.
Viaud, Prof. Manuel Chavez, Apartado 93, Tegucigalpa, Honduras
Vinten, C. R., National Park Service, 23 Water Street, St. Augustine
Volk, Dr. G. M., Soils Dept., Agricultural Experiment Station, Gainesville
Von Waldburg, Anthony, 1716 S.W. 10th St., Ft. Lauderdale
Voorhees, Dr. R. K., Box 3751, Orlando
Wadsworth, Edward A., 201 Lakewood Road, West Palm Beach
Waldo, W. G., P. O. Box 1685, West Palm Beach
Walker, James H., 130-B Catherine Ave., Elinor Village, Pensacola
Walker, Joe E., F.O.A., USDA, Washington 25, D. C.
Walker, Dr. M. N., % American Embassy, Mexico D. F., Mexico
Wallace, Dr. Alvin T., Agr. Expt. Sta., Gainesville
Wallace, Rusell W., North Fla. Expt. Sta., Quincy
Wallis, R. P., 319 Westminster Place, West Palm Beach

Wallis, W. Turner, P. O. Box 1862, West Palm Beach
Walter, Dr. J. M., Gulf Coast Expt. Sta., Bradenton
Wander, Dr. I. W., Citrus Experiment Station, Lake Alfred.
Wardlow, Dwight E., 150 N.W. 9th St., Homestead
Watkins, Marshall O., Agricultural Extension Service, Gainesville
Watson, Harley, P. O. Box 69, Arcadia
Watson, James N., Box 4696, Jacksonville
Webb, Thomas E., North Fla. Expt. Sta., Quincy
Webster, Dr. Raymond H., Dept of Agronomy, Georgia Experiment Station, Experiment, Georgia
Wedgworth, Mrs. Ruth S., Box 206, Belle Glade
Weetman, Dr. L. M., U. S. Sugar Corporation, Clewiston
Wellman, Dr. Frederick L., Instituto Inter-Americano, Turrialba, Costa Rica, Central America
Wells, Stafford L., P. O. Box 687, Homestead
Wertz, Dr. C. F., P. O. Box 316, Coconut Grove Station, Miami 33
Wesson, Harry B, 101 Lake Silver Drive, Apt. 5, Winter Haven
West, Erdman, Dept. of Plant Pathology, Agricultural Experiment Station, Gainesville
Westervelt, Capt. G. C., P. O. Box 239, Indian Town
Westgate, Dr. Philip J., Central Florida Experiment Station, Sanford
Wetherald, C. E., President, U. S. Sugar Corporation, Clewiston
Wheeler, B. F., Wheeler Fertilizer Co., Oviedo
White, Alec, Court House, Tampa
Whitemore, Al H., Box 2111, Orlando
Whittemore, Hiram D., 816½ Ardmore Rd., West Palm Beach
Wilcox, C. B., The Wilcox Grove, Route No. 3, Orlando
Wildman, Dr. E. A., Earlham College, Richmond, Indiana
Will, L. E., P. O. Box 307, Belle Glade
Willard, Dr. C. J., Agron. Dept., Ohio State Univ., Columbus, Ohio
Williams, Lyons H., Jr., 7280 S.W. 54th Court, Miami 43
Williamson, B. F., 549 North Myrtle St., Gainesville
Willis, Stephen P., Farm Editor, Florida Times-Union, Jacksonville
Wilner, William D., 2226 N. Howard St., Baltimore, Md.
Wilson, Claude A., 924 West Columbia Street, Evansville, Indiana
Wilson, Don, P. O. Box 873, Bartow
Wilson, E. Meade, Box 2567, Mulberry
Wilson, J. T., Box 6026, West Palm Beach
Wilson, Robert L., 256 Worth Ave., Palm Beach
Wilson, William C., Sericio Shell para el Agricultor, Cagua, Venezuela, S. A.
Winchester, Oscar R., Boynton
Windsor, Charles J., 13317 W. Lincoln Drive, Huntington Woods, Mich.
Wingfield, C. R., Box 634, Avon Park
Winsberg, Ted, 7401 S.W. 83rd Ct., Miami 43
Winters, Dr. Eric, Univ. of Tenn., Knoxville, Tenn.
Wischhusen, J. F., 15037 Shore Acres Drive, Cleveland, Ohio
Wofford, Dr. I. M., Agr. Expt. Sta., Gainesville
Wolf, Benjamin, 2620 Taylor St., Hollywood
Wolf, Emil A., Everglades Experiment Station, Belle Glade
Wolfe, J. C., Box 310, Tampa 1
Wolff, Dr. Reinhold P., P. O. Box 277, Coral Gables
Wolman, Dr. Abel, Johns Hopkins University, Homewood, Baltimore 18, Md.
Woltz, Dr. S. S., Box 2125, Manatee Sta., Bradenton
Woods, V. E., P. O. Box 734, Davenport
Woodward, Hiram W., 320 Mathieson Building, Baltimore 2, Maryland
Woodward, Robert D., III, Box 267, Quincy
Wright, Jay, Box 653, Orlando
Wright, S. L., Box 215, Crowley, La.
Yothers, Dr. W. W., 457 Boone Street, Orlando
Young, Mrs. Robert R., Fairholme, Ruggles Ave., Newport, R. I.
Young, Dr. T. W., 785 Azalea Lane, Vero Beach
Yount, Fred C., 234 DeSoto St., West Palm Beach
Zemel, Joseph, 605 Lincoln Road, Miami Beach
Zettel, L. F., Montgomery, Illinois
Ziegler, Dr. L. W., Horticulture Dept., Agricultural Experiment Station, Gainesville